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## Editor's Corner

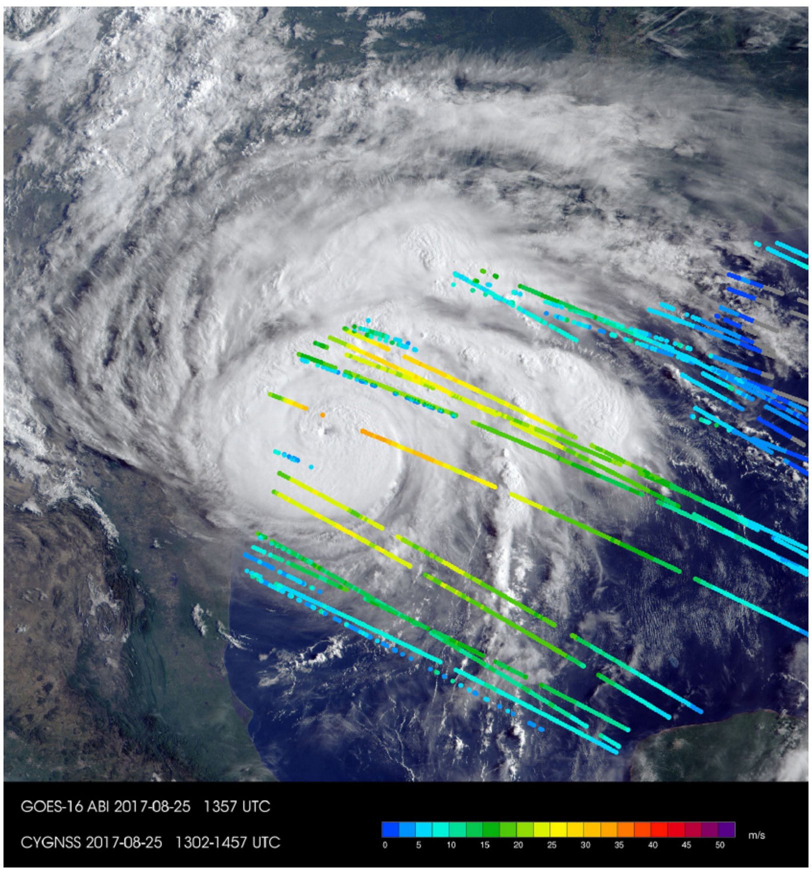
***Steve Platnick***
*EOS Senior Project Scientist*

This has been a period where the natural world has taken center stage, and NASA has been there, providing unique views.

On August 21, 2017, much of North America was treated to a solar eclipse. NASA Television broadcasted the event live from locations all along the path of totality (from Lincoln City, OR to Charleston, SC). The eclipse presented opportunities for unique science observations—including observations related to Earth science. For an immersive account of the 2017 Total Solar Eclipse experience, including a summary of NASA Television's "Eclipse Across America" coverage, perspectives from several individuals who viewed the eclipse across the country, and views of the eclipse from aircraft, Earth-observing satellites, and the International Space Station (ISS), turn to page 4 of this issue.

While the movement of celestial bodies can be predicted with great accuracy, forecasting the movement, and particularly the intensity, of hurricanes remains challenging. The timing of this year's hurricane season coincides with the availability of data from NASA's Cyclone Global Navigation Satellite System (CYGNSS) mission that

continued on page 2




Hurricane Harvey—the first major hurricane to make landfall in the U.S. since Wilma in 2005—was an extremely destructive Atlantic hurricane, causing catastrophic flooding across eastern Texas. In this image, preliminary ocean surface wind speed data observed by the CYGNSS mission between 7:02 and 8:57 AM CST (1302 and 1457 UTC) on August 25, 2017, are overlaid on a Advanced Baseline Imager composite [which was created using a combination of data from two visible bands (A and B) and the infrared band] from GOES-16, acquired at 7:57 AM CST (1357 UTC) the same day. During this time, Harvey was a Category 2 storm with maximum sustained winds of 110 mph (49 m/s). CYGNSS detected surface wind speeds up to roughly 90 mph (40 m/s) near the eyewall (orange), and roughly 83 mph (37 m/s) below some of the outer rainbands northeast of the eye. By 5:00 PM (2300 UTC), Harvey had rapidly intensified into a Category 4 storm, with sustained winds of 130 mph (58 m/s). Observations collected by a suite of instruments onboard NOAA's P-3 "hurricane hunter" on August 25 will be used to help calibrate and validate CYGNSS measurements. Data from CYGNSS will help scientists obtain a better understanding of what causes rapid intensification in tropical cyclones like Hurricane Harvey. **Image credit:** NASA

## In This Issue



**Reminder:** To view newsletter images in color, visit *eospso.nasa.gov/earth-observer-archive.*

launched in December 2016. One of its primary objectives is to collect data that will help improve hurricane intensity forecasts. The 2017 Atlantic hurricane season has certainly provided plenty of such opportunities for CYGNSS. The eight microsatellites that make up the CYGNSS mission have been in position to acquire data in all the recent storms. Preliminary ocean surface wind speed data from CYGNSS are shown on the cover of this issue from Hurricane Harvey with a GOES-16 image underneath. To view an image from the Suomi NPP satellite of three major hurricanes (Irma, Jose, and Katia) active in the Atlantic basin at the same time, turn to page 52.

In addition to hurricanes, two major earthquakes impacted Mexico on September 8 and September 19, 2017. The second of these caused severe damage in Mexico City. NASA's Earth Science Disaster Program has provided a variety of timely datasets useful to stakeholders assessing the impacts of these quakes and land-falling hurricanes. The program promotes the use of Earth science data to improve natural disaster prediction, preparation, response, and recovery. Disaster applications and applied research on natural hazards support emergency preparedness leaders in developing mitigation approaches, such as early warning systems, and providing information and maps to disaster response and recovery teams. To learn more about the program, and to see a full roundup of the datasets NASA provided in response to recent natural disasters, visit *https://disasters.nasa.gov*.

Turning to personnel news, I'm pleased to announce that as of August 6, 2017, **Bryan Duncan** [GSFC] is the Project Scientist for the Aura mission. Duncan has been at GSFC since 2004 in the Atmospheric Chemistry and Dynamics Laboratory. Prior to that he was at UMBC, the Swiss Institute of Technology, and Harvard University. Duncan has expertise in air quality and tropospheric trace gas composition, and is a member of NASA's Health and Air Quality Applied Sciences Team.

Duncan replaces **Anne Douglass** in the role of Project Scientist. Douglass is now in the government's phased retirement program after a distinguished career. She served as Aura Project Scientist starting in 2009, and prior to that had been a Deputy Project Scientist since 1998. **Joanna Joiner** [GSFC] will continue to serve as the Aura Deputy Project Scientist. Many thanks to Douglass for her years of service to Aura and best wishes to Duncan in his new position.

On August 5, 2017, Terra executed a deep space lunar calibration maneuver during which the spacecraft essentially performed a "backflip," allowing MODIS, MISR, and ASTER to view the moon. In the case of MISR and ASTER, it was only the second time during the entire 17-year mission that they observed the lunar surface.[1] (In 2003, a similar maneuver was executed.) Since the surface of the moon is, for all intents and purposes, unchanging over the Terra time period, it can be used as a calibration reference to quantify changes in the instruments. The maneuver will help ensure the quality of some of the longest advanced Earth science satellite datasets available, and allow scientists to have greater confidence in the research analyses and applications that rely on Terra's data. Turn to page 18 of this issue to learn more about this maneuver.

Two new missions are preparing for launch. NOAA's Joint Polar Satellite System-1 (JPSS-1) satellite arrived at Vandenberg Air Force Base in California on September 1, 2017, to begin preparations for launch, which is scheduled for November 10, 2017.

JPSS-1, which will be known as NOAA-20 after launch, is the first in a series of four NOAA next-generation, polar-orbiting weather satellites. It will orbit in the same plane as the joint NOAA–NASA Suomi National Polar-orbiting Partnership (NPP) satellite, with JPSS-1 about 50 minutes ahead. Suomi NPP launched in 2011 as a bridge between several NASA Earth Observing System sensors and those on JPSS. Suomi NPP has been operating as NOAA's primary operational satellite for global weather observations since May 2014.

The sensors on JPSS-1 are similar to existing ones on Suomi NPP: the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite-Nadir (OMPS-N), the Clouds and the Earth's Radiant Energy System (CERES), and the Visible Infrared Imaging Radiometer Suite (VIIRS). For more information on JPSS-1, visit *www.jpss.noaa.gov.*

Finally, the Total Solar and Spectral Irradiance Sensor-1 (TSIS-1) has arrived at NASA's Kennedy Space Center, with a launch to the ISS targeted for no earlier than November 28, 2017, on a SpaceX Falcon 9 rocket. The TSIS-1 mission will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for modeling and understanding solar variability. TSIS-1 will continue the long-term data record of TSI measurements that began in 1978 and is currently being maintained by the TIM instrument on the aging Solar Radiation and Climate Experiment (SORCE) spacecraft (launched in 2003) and augmented (since 2013) by the Total Solar Irradiance Calibration Transfer Experiment (TCTE) instrument, a joint mission with NOAA and the U.S. Air Force. ■

[1] MODIS has the prime positon on the Terra spacecraft, allowing it to peak out of the corner of its field of view and see the moon with the execution of a routine roll maneuver, which is done about once a month. By contrast, for MISR and ASTER to see the moon, the spacecraft must physically flip—which is why it has been done only twice in 17 years. MOPITT and CERES measure radiant energy, so their calibrations do not benefit from a lunar view.

**Undefined Acronyms Used in Editorial and Table of Contents**

| | |
|---|---|
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| CERES | Clouds and the Earth's Radiant Energy System |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt [German Aerospace Center] |
| ESIP | Earth Science Information Partners |
| GFZ | Geoforschungszentrum [German Research Center for Geosciences] |
| GOES-16 | Geostationary Operational Environmental Satellite 16 |
| GSFC | NASA's Goddard Space Flight Center |
| ICESat-2 | Ice, Clouds, and land Elevation Satellite 2 |
| JPL | NASA/Jet Propulsion Laboratory |
| MODIS | Moderate Resolution Imagining Spectroradiometer |
| MOPITT | Measurements of Pollution in the Troposphere |
| MERRA | Modern-Era Retrospective analysis for Research and Applications |
| MISR | Multiangle Imaging Spectroradiometer |
| NOAA | National Oceanic and Atmospheric Administration |
| RAVAN | Radiometer Assessment using Vertically Aligned Nanotubes |
| Suomi NPP | Suomi National Polar-orbiting Partnership |
| TIM | Total Irradiance Monitor |
| UCI | University of California, Irvine |
| UMBC | University of Maryland, Baltimore County |

feature article

# NASA Provides Unique Views of the 2017 "Eclipse Across America"

*Alan B. Ward, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., alan.b.ward@nasa.gov*

*The path of totality... traversed the contiguous U.S. across a narrow strip that made "landfall" in Lincoln City, OR, and exited over Charleston, SC. Locations outside this strip experienced a partial eclipse..., the exact amount of coverage depending on the location.*

## Introduction

On Monday, August 21, 2017, all of North America was treated to an eclipse of the sun, with some locations experiencing a *total solar eclipse*—where the sun was 100% obscured by the moon's shadow, or *umbra*. The *path of totality*—the path that the moon's shadow traces on Earth during a total solar eclipse—traversed the contiguous U.S. across a narrow strip that made "landfall" in Lincoln City, OR, and exited over Charleston, SC. Locations outside this strip experienced a partial eclipse as the moon's *penumbra* passed over them, the exact amount of coverage depending on the location. The last total solar eclipse to occur anywhere over the continental U.S. took place in 1979. The last time the path of totality traversed from coast to coast across the U.S. was in 1918.

Solar eclipses are not uncommon: there is a partial solar eclipse roughly every 6 months, and a total eclipse approximately once every 18 months, visible somewhere on Earth's surface. However, given the size of Earth and that 70% of its surface is covered by ocean, to experience an eclipse—and especially to experience a total solar eclipse—at a particular location on Earth is most unusual...so unusual that for viewers in most locations that experienced totality in 2017, it was a "once-in-a-lifetime" opportunity,[1] both for personally experiencing an eclipse, and also for conducting scientific investigations of the solar atmosphere from Earth. Location rarity aside, the event was the most well-observed solar eclipse ever, with observations being taken by ground-based telescopes and instruments on balloons, aircraft, satellites—and even the International Space Station (ISS).

In addition to its research activities, NASA participated in outreach events all across the country in the days leading up to the eclipse. Because Charleston, SC, was the point where the shadow left the continental U.S., NASA designated it as "Eclipse Central," and anchored its public coverage of the event from Rivers Green on the campus of the College of Charleston (CoC).

This article briefly summarizes NASA Television's *Eclipse Across America* coverage—a four-hour broadcast that took place on the day of the eclipse from 12:00 to 4:00 PM Eastern Daylight Time (EDT).[2] Throughout the summary are discussions of some of the science activities that were conducted, as well as several *Perspectives from the Path* (in shaded boxes) that describe personal anecdotes from eyewitnesses who had been asked to describe their respective eclipse experiences for this article. The **Figure** on page 5 shows a map of the U.S., the path of totality, and all the locations mentioned in the article.

## Eclipse 2017: Through the Eyes of NASA—Summary of NASA Television Eclipse Coverage

At noon EDT on August 21, NASA began its official coverage, "Eclipse 2017: Through the Eyes of NASA." **Dwayne Brown** NASA Headquarters (HQ), Office of Communications (OC)—*Senior Communications Official*] gave a short opening statement and a summary of the upcoming coverage from the main stage of "Eclipse Central," which resembled the set of ESPN's *College GameDay*[3]—complete with an audience of CoC students visible in the background. He then handed the broadcast

[1] This is true for most—but not all—locations. Carbondale, IL, has the unusual good fortune of being in the path of totality for the 2017 eclipse, as well as for the U.S. eclipse in 2024.

[2] To watch the recorded webcast—*Eclipse Across America*—broadcasted from Charleston, SC, and the NASA EDGE coverage—*Live from Carbondale*—broadcasted from Carbondale, IL, visit *https://eclipse2017.nasa.gov/eclipse-live-stream*.

[3] College GameDay is a weekly college football and basketball pregame show typically broadcasted from a different college campus each week, where the "big game" is taking place.

to **Karen Fox** [GSFC, OC—*Lead for Heliophysics*] and **Sean Potter** [NASA HQ, OC—*Certified Broadcast Meteorologist*] who were stationed on Rivers Green (a.k.a., "the quad"). Fox and Potter hosted the preshow for a little over an hour. During this time, Potter gave the first of several updates on weather conditions along the path of totality, showing satellite images of cloud cover from the Geostationary Operational Environmental Satellite (GOES)-16.

The preshow coverage also showed some early views of the partial eclipse through a hydrogen-alpha (H-$\alpha$) filter[4] on a telescope in Salem, OR, and in Madras, OR. They also showed the first images of the total eclipse from NASA's Gulfstream-III (G-III) aircraft flying over the Pacific Ocean near Lincoln City, OR—see *The View from Above—Part I* on page 6. These would be the first of many views of the eclipse during the day, combined with reports about how NASA is using this nominally rare cross-country solar transit to study the sun, Earth, and even other planets.

As the start of totality in Oregon approached, **Yaireska "Yari" Collado–Vega** [GSFC, Space Weather Research Center—*Space Scientist*], **Alex Young** [GSFC—*Associate Director for Science for the Heliophysics Science Division*], and **John Yembrick** [NASA HQ, OC—*Chief of Digital Communications*] joined **Dwayne Brown** on the main stage. Collado–Vega and Young provided science explanations, while Yembrick tracked social media throughout the broadcast. Some 87% of all federal web traffic was tuned to the NASA eclipse coverage, and at 1:40 PM EDT, 4.4-million people were tuning in to what became the biggest livestream event ever on *nasa.gov*. Yembrick showed numerous tweets and images of the eclipse that were posted throughout the broadcast, which included appearances from viewers and active scientists stationed across the country, and even one flying over the Pacific Ocean. Yembrick showed numerous tweets and images of the eclipse that were posted throughout the broadcast, which included appearances from viewers and active scientists stationed across the country, and even one flying over the Pacific Ocean.

*Some 87% of all federal web traffic was tuned to the NASA eclipse coverage, and at 1:40 PM EDT, 4.4-million people were tuning in to what became the biggest livestream event ever on **nasa.gov**.*

In the material that follows, the earlier-referenced anecdotal experiences and highlights from the broadcast capture the excitement. While not chronological, the descriptions are provided approximately from west-to-east.

[4] A hydrogen-alpha (H-$\alpha$) lens is the most common filter used for viewing the sun. It removes all light except that which is emitted by hydrogen (by far the most common element on the sun), which emits in the red end of the visible spectrum (656.3 nm). Filtering out all light other than what is emitted by hydrogen has an effect similar to that of an eclipse, and allows for observation of the solar atmosphere (i.e., the chromosphere and corona). Most of the views of the sun shown during the broadcast were either white light (which shows the photosphere) or through H–$\alpha$ lenses.

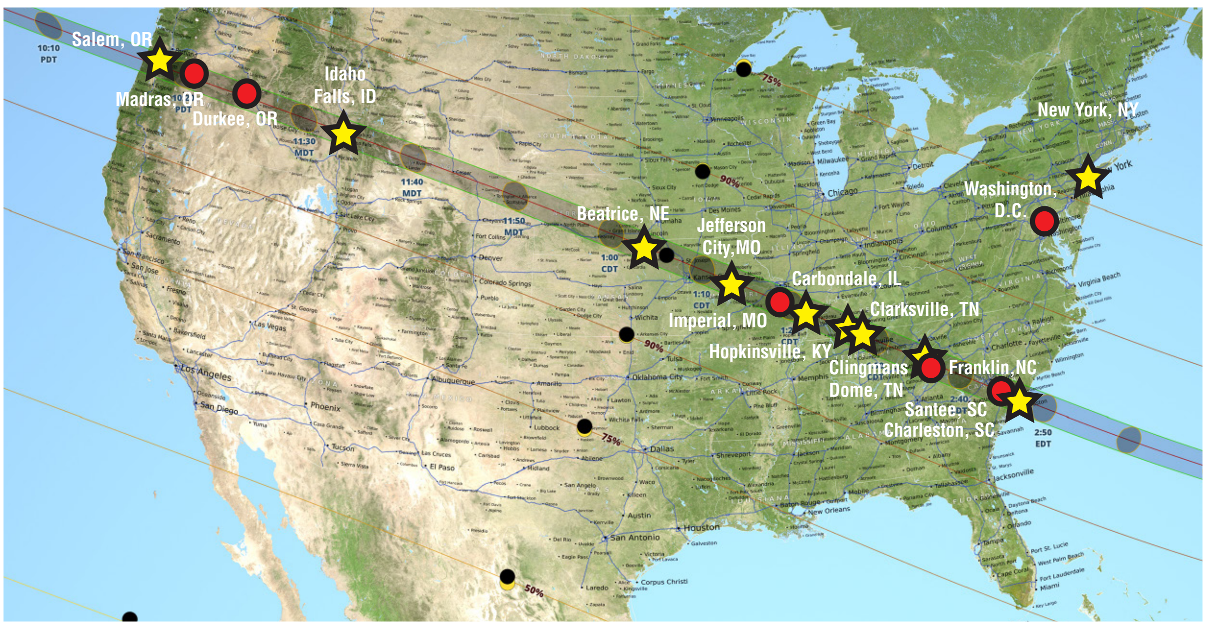



**Figure.** Shown here on this map of North America is the path of totality for the 2017 solar eclipse. Locations mentioned in the article are shown. Spots shown during the NASA Television coverage are shown as yellow stars; other locations mentioned in the article are shown as red circles. Lines mapping the maximum percentage of totality (90, 75, 50) are marked for areas outside the path of totality. **Image credit:** NASA feature article

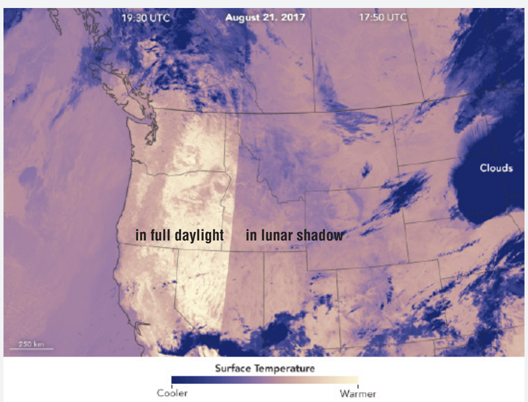
## The View from Above—Part I: NASA's WB-57 Aircraft and Earth Observing Satellites View the Solar Eclipse

The first NASA images of the total eclipse over the U.S.—including the first views of the *Baily's Beads*, and *diamond ring*, effects (diamond ring effect shown in photo; both defined in footnote 5)—came prior to "U.S. landfall" from an instrument on NASA's Gulfstream-III (G-III) aircraft based at NASA's Armstrong Research Center, which was flying off the coast of Oregon. This aircraft was specially equipped for viewing the eclipse, with newly installed optical-grade windows and a telemetry system that allowed high-resolution video to be obtained and streamed live over the Internet from its origin at 35,000 ft (~10.7 km). The aircraft flew a racetrack pattern over Lincoln City, OR—the first U.S. city to experience totality.

NASA 's Gulfstream-III aircraft obtained this image of the diamond ring effect as it flew off the Pacific coast near Lincoln City, OR, on August 21, 2017. As the last bits of sunlight passed through valleys on the moon's limb, the faint corona around the sun was just becoming visible, giving the sun the appearance of a diamond ring. **Image credit:** NASA's Earth Observatory

During the NASA TV coverage, **Kevin Rohrer** [NASA's Armstrong Research Center] interviewed **Robert Lightfoot** [NASA Headquarters (HQ)—*Acting NASA Administrator*] and **Thomas Zurbuchen** [NASA HQ—*Associate Administrator for the Science Mission Directorate*], asking for their thoughts on observing a solar eclipse from above Earth's surface. **Zurbuchen** discussed some of the science conducted on the G-III. He stated that the eclipse gives the agency a chance to "see our star as a magnetic star," and a rare opportunity to take measurements of the solar magnetic field. He also talked about spectroscopic measurements of the sun's atmosphere (corona) that the instruments on the G-III obtained just before the moment of totality, showing distinctive lines that represent helium, iron, and hydrogen in the sun's atmosphere.[*] The G-III also took incoming radiation measurements to document their respective decreases during the eclipse, and to assess the impact on Earth, below. Zurbuchen has researched the corona for 25 years, but this was his first chance to see it *live,* and he was amazed. **Lightfoot** described his experience watching the moon's shadow envelop the Oregon coast from the window of the G-III, which allowed viewing both sunlight and shadowed regions simultaneously, and to watch the shadow move. He likened it to watching a thunderstorm move across the plains. He complemented the G-III team for doing an outstanding job, coordinating the flight and observations.

In addition to aircraft observations, several Earth-observing satellites viewed the eclipse from polar orbit, 443 mi (~713 km) above Earth. NASA's Terra (see image below) and Aqua platforms and the joint National Oceanic and Atmospheric Administration (NOAA)–NASA Suomi National Polar-orbiting Partnership (NPP) mission all captured visible imagery that was used to track changes in the surface temperature (shown below) as the moon's shadow passed over the U.S. From much further away, the Earth Polychromic Imaging Camera (EPIC) on the Deep Space Climate Observatory (DSCOVR) also captured images of the shadow moving across the Earth.[**] Several images and animations made using data from Earth-observing satellites can be viewed at *https://earthobservatory.nasa.gov/IOTD/view.php?id=90796.*




[*Left*] As the lunar shadow moved across the surface, Earth observing satellites detected a decrease in surface temperatures. This image shows surface temperatures as measured by Terra's MODIS on August 21, 2017. Note the clear line between these two Terra overpasses on the day of the eclipse, one taken in full daylight before the eclipse began, and the other during the eclipse. Land surface temperatures were significantly cooler (dark purple) in the central U.S. at 12:50 PM (1750 UTC) on August 21, 2017, when Terra collected imagery of the shadow. **Credit**: NASA's Earth Observatory

[*] A spectrograph essentially decomposes white light into its component colors and is a useful means of determining the chemical composition of the atmosphere of the sun, Earth, or other celestial bodies.

[**] EPIC views the full Earth continuously from L1 Lagrange Point, approximately one million miles from Earth. The NASA TV coverage included an EPIC animation of the moon shadow during the March 2016 solar eclipse over Indonesia. It can be viewed at *https://svsdev.gsfc.nasa.gov/30758.*

*Salem, OR*

**Jesse Carpenter** [NASA's Ames Research Center—*Videographer*] was located at the Oregon State Fairgrounds in Salem. As the eclipse progressed, Carpenter interviewed **Nicholene Viall** [GSFC—*Solar Physicist*] who emphasized how unique today's view of the eclipse would be. She explained that while solar observatories in orbit [e.g., the Solar Heliospheric Observatory (SOHO)] routinely create "artificial" eclipses [using a solid disk mounted on the detector, allowing them to observe the sun's atmosphere (or *corona*)], they still cannot see the *inner corona*—the region of the sun's atmosphere just above the sun's surface, or *photosphere*. The inner corona is of particular interest to scientists because it is where violent solar storms gather energy, until they burst forth as coronal mass ejections. This innermost layer of the sun can only be glimpsed from Earth during the fleeting moments of totality during a solar eclipse.

As the moment of totality approached Salem, Carpenter interviewed **Madhulika "Lika" Guhathakurta** [NASA HQ—*NASA Lead Scientist for Eclipse 2017* and *Lead Scientist for Living with a Star Program*]. Guhathakurta talked about the importance of studying the corona to understand space weather, and how today was a rare chance to view the corona from Earth. Despite the fact that she was a veteran of solar eclipses—having seen six and attended three more where inclement weather prevented viewing—she was clearly still very moved by what she watched unfold in the sky above her in Salem.

> *"[Today's events remind us] that we live in the outer atmosphere of a magnificent, dynamic, magnetically variable star, that dominates every cubic inch of our solar system."*
>
> —**Madhulika "Lika" Guhathakurta** [*NASA Lead Scientist for Eclipse 2017*].

## Clouds in a Bottle—but Smoke-Free Skies Above

*Madras, OR*—**Tassia Owen** [GSFC—*Terra Mission Communications Lead, Science Writer*]

Clouds aren't common in the skies over central Oregon in summer, so I brought some "in a bottle." At the Oregon Solar Fest, I created these "instant clouds" inside clear, two-liter bottles as part of a demonstration to show the capabilities of the science app, *GLOBE*[*] *Observer—https://scool.larc.nasa.gov/cgi-bin/view_lesson-plan.cgi?id=87*. Of course, scientists typically don't study clouds in a bottle, but instead use satellite images and pictures from citizen scientists to get more information about what is happening in the sky. GLOBE Observer created a cloud and temperature measurement protocol for the eclipse. I recruited new citizen scientists, answered questions about how the app works, and then, as the moon began to eclipse the sun, the sky turned dark, and the air turned cold, I used the app to track its impact by entering temperature and cloud data into the app. Scientists can then reference the data to see how temperatures dropped and to see if cloud cover changed throughout the eclipse.[**]

The sun above us seemed to sail on the smoke of nearby wildfires, always threatening to obscure totality. On August 21, 2017, smoke settled near the horizon—but clear skies prevailed above! Surrounded by 5500 campsites and an additional few thousand "day trippers" in a farmer's field, people cheered in excitement, hushed in anticipation, and exhaled in collective awe as the sky dimmed and we stood together in the moon's shadow. As I looked around, I saw my six-year-old and four-year-old children, mesmerized by nature and brimming with questions. Perhaps this was the moment that two young scientists were made? Fortunately for them, the 11.5-hour drive home provided plenty of time to answer many of their questions.

[*] GLOBE stands for Global Learning and Observations to Benefit the Environment. It is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of the Earth system and global environment. To learn more, visit *https://www.globe.gov*. To view/download the GLOBE Observer app, visit *https://observer.globe.gov*.

[**] To view an animation of the air temperature data collected during the eclipse at 15 minute intervals visit *https://observer.globe.gov/science-connections/eclipse2017*.

## Two Minutes on the Dark Side of the Moon

*Durkee, OR*—**Sally Bensusen** [GSFC/GST—*Graphic Artist*]

Good sky. Sharp and clear. My husband Jonathan and I arrived early—just off Interstate 84—and parked at the gravel-paved lot across from the Ranch Hand Café, along with a few hundred other eclipse chasers. Of course, I would watch the progression of the eclipse with everyone. But I really wanted to capture a different perspective: I would try to record the moon's shadow, as it raced over the landscape toward us at over 2000 miles per hour.

*Two and a half minutes before totality*. I pointed my cell phone due west toward Lincoln City, the first town on the Oregon coast to witness this eclipse, and started taking video. I had a clear shot of low hills in the distance. The color of the landscape began to shift. I waited. The events here correspond to times on my video:

*0:30*. A school bus zooms by on the interstate toward Baker City. Colors flatten.

*1:22*. The blue sky deepens.

*1:40*. The horizon turns white. The first hill dims slightly. Then, things happen fast.

*1:55*. The farthest hill is in light shadow.

*1:58*. Now we're in light shadow; the hill goes dark, then us; the crowd roars, "OH!" I whip around to catch the last rays on video and the diamond ring catches my eye before it disappears! OW! So bright!

*Darkness*. Totality. The crowd clapped, whooped, cheered. We were immersed in a tinny light, a color I wasn't prepared for. No one was. It wasn't night, or day. The sun was dressed in black, wearing a necklace almost too bright to gaze at. A softer corona bled outward, beyond that. I couldn't wrap my head around this picture. It was wrong. Beautiful. Disturbing. Stunning. We only had two minutes to take it all in.

Then, it was over. The moon's shadow sped off towards the southeast. The sun's brilliant face was again unveiled. The world was still here…

Just enough time to catch our plane.

*Idaho Falls, ID*

**Gay Yee Hill** [JPL—*Media Relations Specialist*] summarized outreach activities going on at the Museum of Idaho. NASA partnered with the museum to organize presentations, demonstrations, visualizations, and artwork—all leading up to the eclipse. Solar System Ambassadors (*https://solarsystem.nasa.gov/ssa/home.cfm*) were stationed all along the path of totality to help promote this event.

*As a seasoned scientist, Green could explain exactly what was about to happen—yet he still got excited as he experienced it himself: "Look at the ray structure! You can't get that on film!… There's Venus! There's Venus!… WOW!"*

Hill interviewed **Jim Green** [NASA HQ—*Director of Planetary Sciences*], who described planetary experiments on some of the balloon launches—see *NASA's Eclipse Ballooning Project* on page 10—and how eclipses offer rare opportunities for planetary science explorations. Thirty of the balloons launched carried a planetary science experiment to see if *Paenibacillus* bacteria can survive at high altitudes. Two small aluminum strips, called *coupons*, were coated with a thin film of the bacterium and used in the experiment: one stayed at the surface; the other was launched with the balloon. He explained that at 100,000 ft (~30.5 km), the balloon is above the protective ozone layer, and the atmospheric conditions (e.g., ultraviolet exposure, temperature, pressure) resemble those that would be encountered on the Martian surface. Planetary scientists can use this as a *Mars analog*, to figure out if *Paenibacillus*, which is ubiquitous on Earth, could survive on the surface of Mars.

As Hill and Green talked, the moment of totality approached Idaho Falls. As a seasoned scientist, Green could explain exactly what was about to happen—yet he still got excited as he experienced it himself: "Look at the ray structure! You can't get that on film!… There's Venus! There's Venus!…WOW!" After another minute or so they saw the *Baily's Beads* and *diamond ring* effects[5] just prior to totality. A few minutes later they saw the diamond ring on the other side, and it was time to put back on their protective glasses.

*Beatrice, NE*

A native Nebraskan, **Jen Rae Wang** [NASA HQ—*Associate Administrator for NASA's Office of Communications*] appeared on the set from Charleston, and shared her personal excitement about both the total eclipse as it was happening in her home state and NASA's collective excitement at this rare opportunity to observe the sun's corona. She then handed the coverage off to **Vince Whitfield** [NASA's Langley Research Center] who reported from the Homestead National Monument of America (NMA) in Beatrice, where the National Park Service (NPS) coordinated an eclipse-viewing activity. He spoke with **Susan Cook** [NPS—*Chief Park Ranger*] discussed the Homestead NMA, which is dedicated to telling the story of homesteading and the important role homesteading played in the settlement of the West. She also explained how the *Maya calendar* (used by Ancient Mayans) is organized and how the secular (*haab*) and spiritual calendars (*tzolkin*) have strong roots in the motion of the sun and moon.[6]

Whitfield next talked with **Nicky Fox** [Johns Hopkins University, Applied Physics Lab—*Parker Solar Probe[7] Project Scientist*] who, like many, was witnessing her first solar eclipse. Fox explained that the Parker Solar Probe's mission has been considered for decades, but certain components (e.g., the heat shielding) had only recently become technologically feasible.

Although there was cloud cover over Beatrice at the time, totality engulfed the prairie, and the chromosphere and corona could be seen through the clouds for about two minutes before the diamond ring emerged. Fox became quite emotional as she described the science behind what she was witnessing—as theoretical knowledge intersected with personal experience: "And you *can* see the corona! I may cry."

*Fox became quite emotional as she described the science behind what she was witnessing—as theoretical knowledge intersected with personal experience: "And you can see the corona! I may cry."*

*Carbondale, IL*

**Kevin Boucher** [NASA's Langley Research Center, NASA EDGE[8]] was at Saluki Stadium on the campus of Illinois State University, where he interviewed **Gregory Guzik** [Louisiana State University (LSU)—*Physics Professor, Director of Louisiana Space Grant Consortium (LSGC)*] and **Colleen Fava** [LSU, LSGC—*Program Manager*] who explained the plans for the balloon launches the payload, and and plans for payload retrieval. LSGC was one of 55 coordinated teams conducting balloon launches across the U.S. that day as part of the Eclipse Ballooning Project described on page 10.

[5] The *Baily's Beads* effect occurs during a solar eclipse, just seconds prior to totality, as the rugged lunar limb topography allows the final rays of sunlight to shine through in some places, and not in others. The phenomenon is named in honor of Francis Baily, who provided an exact explanation of the phenomenon in 1836. The *diamond ring* effect occurs immediately before totality, as the corona comes into view, when only one very bright bead is left, resulting in what appears to be a shining diamond set in a bright ring around the lunar silhouette.

[6] The Maya calendar is a system of three interlacing calendars and almanacs: the *haab* is 365-day secular—and solar—calendar; the *tzolkin* is a 260-day divine calendar—with eclipses occurring every 173 days, so that every 3 sequences of eclipses aligns with every 2 cycles of the tzolkin; and the long count is an astronomical or universal calendar that lasts ~7885 years. To learn more, see *https://www.timeanddate.com/calendar/mayan.html*.

[7] The Parker Solar Probe (*https://www.nasa.gov/content/goddard/parker-solar-probe*) will launch in 2018. Dubbed the first mission to "touch the sun," the probe will travel directly into the sun's atmosphere to within 4 million miles of the solar surface. To place this vast solar distance in perspective, if the distance between the probe and the solar surface were placed on the scale of a 100-yard football field and the surface was the goal line, the probe would be located on the four-yard line.

[8] NASA Edge had separate coverage of the eclipse based out of Carbondale (available at the same website as the NASA TV live stream referenced earlier). NASA TV coverage intersected with NASA Edge coverage for reports from Carbondale.

*Carbondale did not have a clear view of the eclipse during totality. The good news is they get another chance in 2024!*

The coverage later showed a view of the occluding solar disk over Carbondale through a calcium-K (Ca-K) filter on a telescope. In contrast to the H-α views shown elsewhere, this filter focuses the blue end of the visible spectrum—nearly in the ultraviolet (393.4 nm). When viewed in blue light, several *sunspots*[9] on the solar surface became apparent that weren't visible in the red light of the H-α lens. Unfortunately, however, Carbondale did not have a clear view of the eclipse during totality. The good news is they get another chance in 2024!

[9] Sunspots are regions of super intense magnetic activity on the sun's surface that are the source regions for space weather.

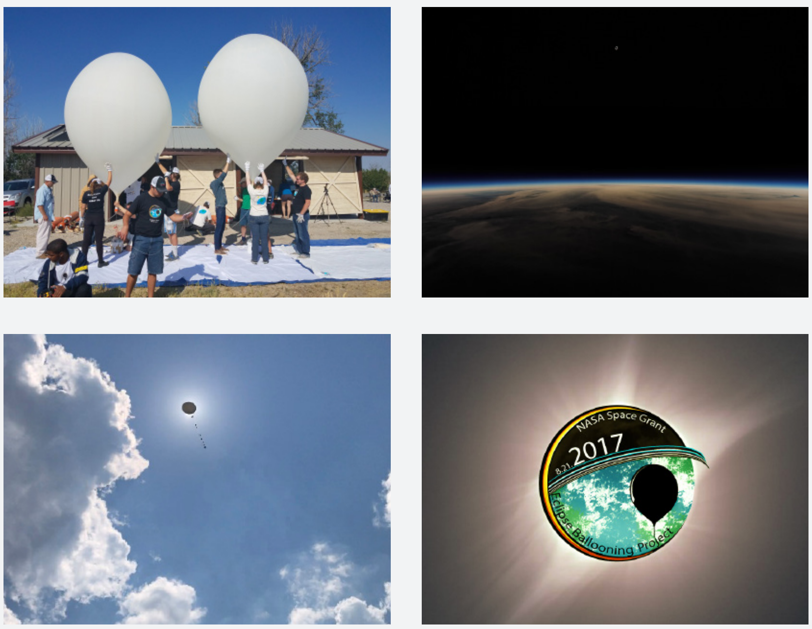
## NASA's Eclipse Ballooning Project

The Eclipse Ballooning Project (*http://eclipse.montana.edu*) was a nationwide collaborative effort organized by Montana State University (MSU)—Bozeman, to live-stream footage of the August 21, 2017, total solar eclipse from the edge of space—a vantage point never before achieved across such a wide swath of the country. The project consisted of 55 teams of students at universities, high schools, and high-altitude ballooning groups—a number of which are mentioned in this article. Along the path of totality on eclipse day, the teams flew payloads on about 100 high-altitude balloons, including payloads that streamed live video to the Internet.

At approximately 9:15 AM Pacific Daylight Time (12:15 PM EDT), participants launched the first weather balloon from a research vessel in the Pacific Ocean, giving the public one of the first glimpses of the moon's shadow as it raced towards the Oregon coast. Other teams followed suit with precision timing—from Oregon, Idaho, Wyoming, Nebraska, Missouri, Illinois, Kentucky, Tennessee, and the Carolinas. The Stall High School team in South Carolina obtained the last balloon observation of the day, from an altitude of 96,000 ft (~29.3 km) at around 3:27 EDT.

The project utilized cutting-edge technology, including Iridium and GPS satellites, lightweight radio modems, miniature computers, and live-streaming video. The balloons ascended to about 100,000 ft (~30.5 km) above Earth's surface. From this vantage point at the edge of space, the live video showed the curvature of Earth and the blackness of space, and images of the moon moving in front of the sun's disk. Some of the footage obtained is posted at the website referenced above.

In addition to the common camera, payloads on all balloons provided near-real-time footage of the moon's shadow on Earth and the darkened sun, and many teams flew secondary payloads of their own design—e.g., the planetary science experiment **Jim Green** described on page 8. Links to information and pictures about each team's secondary payload are included online—*http://eclipse.montana.edu/teams*.




On August 21, 2017, 55 teams around the U.S. launched balloons as part of the Eclipse Ballooning Project. Shown here: the team from Montana State University launches their balloons [*top left*]; one of the balloons launched by the University of Maine Balloon team rises through the atmosphere [*bottom left*]; a view of the distant corona from ~100,000 ft obtained by one of the Portland State University team's balloons [*top right*]; and the Eclipse Ballooning Project Logo [*bottom right*]. **Image credits:** Montana State University Eclipse Ballooning Project

## An Imperial View of the Eclipse

Imperial, MO—**Amy Moran** [GSFC/GST—*Animator*]

I watched the eclipse at my brother's house with his friends and neighbors. My brother is a photographer and I'm an animator, so one of the main things that struck us was the quality of the light. There was a visible change starting about 20 minutes before totality. The light had almost a greenish tint to it, and shadows seemed to get knife sharp. We couldn't stop taking pictures of arc-shaped shadows everywhere.

As the moon started occluding the sun more and more, it got strangely quiet and blissfully cooler (considering it started at 94 °F). My hair stood on end watching the last sliver of sun slip away and then seeing the ring of the eclipse. The crickets started chirping, street lamps popped on, and the neighbor's dog wouldn't stop barking. The cat, on the other hand, continued sleeping wherever she was, as cats are wont to do. As totality passed, the light returning to the shadows shimmered almost like the caustics at the bottom of a pool, and it became daylight faster than any of us expected. Thankfully, it continued to cool down for a while longer, all the way down to 84 °F, which is downright pleasant for summer near St. Louis.

*Jefferson City, MO*

**Eric Aldrich** [University of Missouri, Columbia (UM)—*Professor of Atmospheric Science, Meteorologist*] covered activities from the state capital of the Show-Me State. (Aldrich's UM team was among those releasing weather balloons as part of NASA's Eclipse Ballooning Project.) Aldrich interviewed former NASA Astronaut **Janet Kavandi** [Director of NASA's Glenn Research Center] from Springfield, MO, who is a veteran of three Space Shuttle missions. As an astronaut, Kavandi had seen partial eclipses from space before, but she had never seen a total eclipse. She remarked that it was a totally different experience seeing it from the ground.

Aldrich also interviewed **Tamitha Skov** [Aerospace Corporation—*Research Scientist*] who does a weekly broadcast on space weather prediction, and is known as the "Space Weather Woman." While they were talking, totality occurred over Jefferson City. The clear skies above allowed a great view of the diamond ring and corona; crickets could be heard in the background and street lights came on.

*Clarksville, TN*

**Christopher Blair** [NASA's Marshall Space Flight Center (MSFC)] reported from a working farm on the campus of Austin Peay State University (APSU) in Clarksville. As in Carbondale, there was a team launching three balloons here in conjunction with the NASA Eclipse Ballooning Project. **Dominic Critchlow** [APSU] described the scientific payload on the balloons his team launched—see page 10 for details on project and payload. The APSU launch was one of the 33 equipped with the planetary science experiment that Jim Green described in Idaho Falls.

Blair then handed coverage to **Mitzie Adams** [MSFC] who discussed the atmospheric and animal science experiments being conducted by students from around the country, including teams from MSFC's U.S. Space and Rocket Center (a.k.a., Space Camp) and the Interdisciplinary National Science Project Incorporating Research and Education Experience (INSPIRE) Project (which is conducting very-low-radio-frequency noise experiments). Adams's parting words to Blair included her wish for the next American eclipse in 2024, which was the same that the late Frank Reynolds [ABC News] wished for the world in 2017 back in 1979: Near the end of the ABC News special coverage of the 1979 total solar eclipse (the last to cross the U.S. soil before this one), Reynolds said: "May the shadow of the moon fall on a world at peace." May it be so.

*"May the shadow of the moon fall on a world at peace."*
*—**Frank Reynolds** [ABC News Eclipse Coverage, 1979]*

## Every Cloud Has a Silver Lining

*Franklin, NC*—**Alan Ward** [GSFC/GST—*Science Writer*]

My family's eclipse pilgrimage bought us to Franklin, NC. We drove over eight hours from our home in Maryland to the Great Smoky Mountains—and then 45 minutes further west on the morning of the eclipse—to place us smack-dab in the middle of the *path of totality*. This rare event was a big deal for this small town. They had an "Eclipse Block Party" on Main Street to occupy us (and thousands of our "closest friends") while we waited for the celestial main event to begin. The town showed the live stream of the NASA TV coverage in the Chamber of Commerce building beginning at noon. We watched totality unfold in Salem, OR, and later I peeked in just as the diamond ring emerged over Jefferson City, MO. Just seeing these scenes on the screen was enough to whet my appetite for what I would soon see *live* in the sky above Franklin.

Alan Ward views the eclipse through a telescope in Franklin, NC. **Photo credit:** Alan Ward

Cumulus clouds are almost inevitable in the Great Smoky Mountains on a summer day. I noticed them lurking on the horizon throughout the morning and early afternoon, but the sky above us remained clear. Throughout the afternoon, we watched through our eclipse glasses as the moon's shadow slowly enveloped the solar disk. As totality drew near, my daughter and I peeked through a safely configured telescope someone had set up on the lawn. That's when I first noticed the stratocumulus cloud deck lurking overhead, and it became increasingly difficult to find the solar disk through the clouds. I admit it: The thought of coming all this way and not having clear skies to view the eclipse was discouraging.

As totality engulfed us, it got dark and the temperature dropped noticeably. It was strange to see the lights on the Chamber of Commerce building come on for a few minutes in the middle of the afternoon, and to hear crickets in the trees and bushes near us. I *knew* these things would happen; but (as others in this article have noted) *knowing* the science of an eclipse isn't the same as *experiencing* it in person. Furthermore, seeing an eclipse with a group of people is simply electrifying.

The "cloudy corona" seen through the lens of an iPhone-6. **Photo credit:** Laurie Gates–Ward

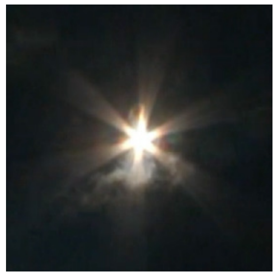
Just as I was losing hope that we would see the sun at all during totality the clouds thinned just enough to reveal the elusive object of our quest at just the right moment, when it was safe to take off our glasses and look directly at what we had carefully avoided all afternoon. Suddenly we saw a halo around the darkened sun. The partially obscured view of the corona that emerged was a thing of beauty (see photo—*right*). I remember hearing the gasps and cheers throughout the crowd as we watched it all unfold—together.

The time to look directly at it and take photos was fleeting; after what seemed like two seconds (but was actually more like two minutes) someone shot fireworks, which we surmised was the sign that totality passed and that we had to don our glasses again. The apparent black hole cover over the sun slowly began to recede, and as it did, the crowds in Franklin rapidly began to disperse.

While totality may not have been quite as dramatic as I dreamed it would be (or as it was in some of the images I saw on NASA TV from across the country), we still had a unique eclipse experience in Franklin. We may not have had a pristine view of the corona, but it was *our* view. The old saying, "every cloud has a silver lining," now has new meaning for me.

*Hopkinsville, KY*

**Brian Massey** [GSFC, OC] reported from a farm near Hopkinsville. He interviewed **Renee Weber** [MSFC—*Planetary Scientist*] who described the view from Hopkinsville as the *point of greatest eclipse*—when the axis of the moon's shadow points most directly towards Earth's center, meaning totality lasted longer here than anywhere else. As a result, Hopkinsville had proclaimed itself "Eclipseville U.S.A." This also meant that the moon's shadow at this location was the most circular of any location. Weber's lunar-studies focus gave her the opportunity to remind everyone that the "real star of a solar eclipse is the moon." As they spoke an eerie dimness engulfed them. Weber described her experience of totality, mentioning that the horizon got pink (like at dawn or dusk), followed by the diamond ring, and then Baily's Beads. They saw the sun's corona—and Jupiter—in the middle of the afternoon! Weber remarked, "It's one thing to read about it, but it's another when you get to see it with your own eyes."



Unfiltered view of the eclipse from the highest point in Tennessee. **Photo credit**: NASA

*Clingman's Dome, TN*

NASA showed the view from the highest point in Tennessee, located in Great Smoky Mountains National Park, which is the largest national park east of the Rockies. This image was different from the previous telescope views, which were through H-α or Ca-K lenses that filtered the light. Because the camera is not filtered, the image looked more like a "Christmas star" that diminished in size until it vanished, leaving behind a distant image of the corona. Alex Young commented that this unfiltered telescope image was the closest to what one sees when viewing an eclipse with the naked eye.

When it comes to viewing eclipses, sometimes a few miles can make a big difference. While clouds in the skies directly above Charleston partially obscured the view of totality, about an hour away, in Santee, SC (near Lake Marion), skies were clear, allowing for an exceptional view of the corona through the lens of a Canon-7D camera (with a zoom lens at maximum magnification). **Photo credit**: Larry Roelofs [GST—*Cofounder*]

*New York City, NY*

New York City was not in the path of totality, but there was a live stream of NASA TV's coverage broadcast on a large screen set up in Times Square. Broadcasting from Charleston, Alex Young explained that in January 1925 the path of totality of a solar eclipse indeed passed over the Big Apple, and residents between 95th and 97th streets were directly in the path. Young also explained that the 1925 event was one of the first eclipses where scientific investigations were conducted, as the U.S. Naval Service launched two dirigibles to conduct experiments to see if eclipses created radio waves that interfered with communications on Earth. Interference was observed, but we have subsequently learned that it was the sun itself (i.e., space weather) that caused the interference.

*Charleston, SC*

The crew that had been anchoring coverage on the set joined Sean Potter out on the quad as totality approached the CoC. The partial eclipse could be seen through the cloud cover, but that cover obscured the full view of the solar disk around totality. Nonetheless, darkness descended on Charleston and temperatures dropped—and the crowd and television hosts reacted with awe to what they witnessed as they saw the eclipse's totality with their naked eyes.

## An Obscured View of the Sun…but a Total Eclipse Nonetheless

*Charleston, SC*—**Steve Graham** [NASA/GST—*Senior Exhibits Specialist*]

I was in Charleston supporting the NASA eclipse outreach events. As totality approached, we all went outside to the lawn of Rivers Green to watch the live broadcast and the event itself. It was cloudy most of the day, but we were able to get glimpses of the event as the clouds thinned and we were able to view the sun with our glasses. But as soon as totality hit, a low cloud deck moved in on our view of the sun and we did not get much of a view. While this was certainly a disappointment, it still got quite dark. We didn't get the full effect because of the low clouds and all the lights that were reflecting off them back to the surface. At least it didn't rain where we were. Other parts of Charleston had thunderstorms and rain during the event.

Definitely looking forward to 2024!

## A Partial Eclipse of the Heart

*Washington, DC*—**Heather Hanson** [GSFC/GST—*Science Writer*]

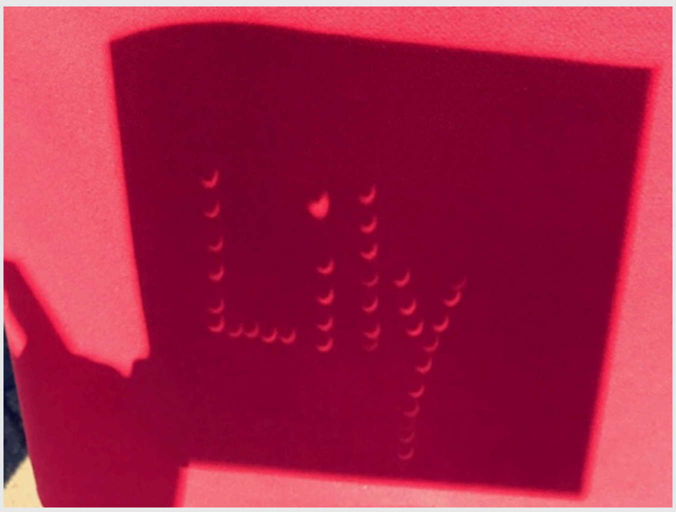
As soon as the exhibit hall opened at the American Chemical Society's National Meeting and Exposition on the day of the eclipse, attendees streamed down the escalators of the Walter E. Washington Convention Center and headed towards the NASA exhibit with only one exciting topic on their minds—the solar eclipse! Even before they reached the exhibit, questions swirled: "Are you giving away solar-viewing glasses?" "What time does the eclipse start?" "What will it look like here in DC?" "How dark is it going to get?" Like the thrill associated with the release of a new *Harry Potter* film, people were curious about the much-anticipated, seemingly theatrical phenomenon that they were about to experience.

The exhibit featured the NASA Hyperwall, two large displays that showed the detailed path of the eclipse, and tables with eclipse- and chemistry-related publications. At 10:30 AM EDT, **Jack Kaye** [NASA Headquarters—*Associate Director of Research for the Earth Science Division*] gave a Hyperwall talk titled "Viewing the Eclipse and Earth." His talk attracted a large, standing-room-only crowd as he showed a variety of eclipse-path visualizations and showed what an eclipse shadow on Earth looked like from two different perspectives in space—from a satellite at the first Lagrange Point [the Deep Space Climate Observatory (DSCOVR)] and one in geostationary orbit (the Himawari-8, a Japanese weather spacecraft).

Beginning at noon, the NASA TV live stream was broadcast on the Hyperwall. Attendees sat for hours, watching the eclipsed sun's shadow make its way across the states. Each time NASA TV broadcast from a new city along the path of totality just minutes before and during total darkness, a crescendo of excitement washed over the attendees. I got chills each time! The energy and enthusiasm in the room almost—almost!—matched the energy and enthusiasm on the other side of the broadcast.

In Washington, DC, the partial eclipse began at 1:17 PM and peaked at 2:42 PM, when the moon covered 81% of the sun. I snuck outside at 1:17 PM to witness the start of the event. I couldn't notice any difference in sunlight, but when I gazed up at the sun, proudly wearing my NASA-provided solar-viewing glasses, I squealed with excitement! I looked up a few more times before heading back to the exhibit hall. By 2:30 PM, most of the exhibit hall attendees had headed outdoors. My two colleagues and I hurried up the escalators from the exhibit's basement location. As we made our ascent, I noticed the dim appearance of the window-filled foyer. Just outside the entryway doors, hundreds of people flooded the sidewalk. As we made our way through the crowd, I noticed and could almost *feel* the dimness of the sky. Everything sort of took on a gray hue, almost like we were in a movie from the 1950s.

From our tiny spot on the sidewalk, we giddily viewed the eclipsed sun. Fumbling with our cameras, solar-viewing glasses, and homemade pinhole projectors, we took turns snapping photos and holding up our art projects. I had embellished a thick piece of cardstock paper with tiny pinholes that spelled out my daughter's name—Lily (see photo). After capturing the perfect camera shot of her name outlined in tiny crescent shadows, my eclipse experience felt complete, and I was thrilled! To witness the power of science bringing together so many—elbow-to-elbow on a tiny sidewalk in our nation's capital—was invigorating. As we headed back inside, like many I couldn't help but sing Bonnie Tyler's "Total Eclipse of the Heart." For me, it was a *partial eclipse of the heart*! And an experience I'll never forget.



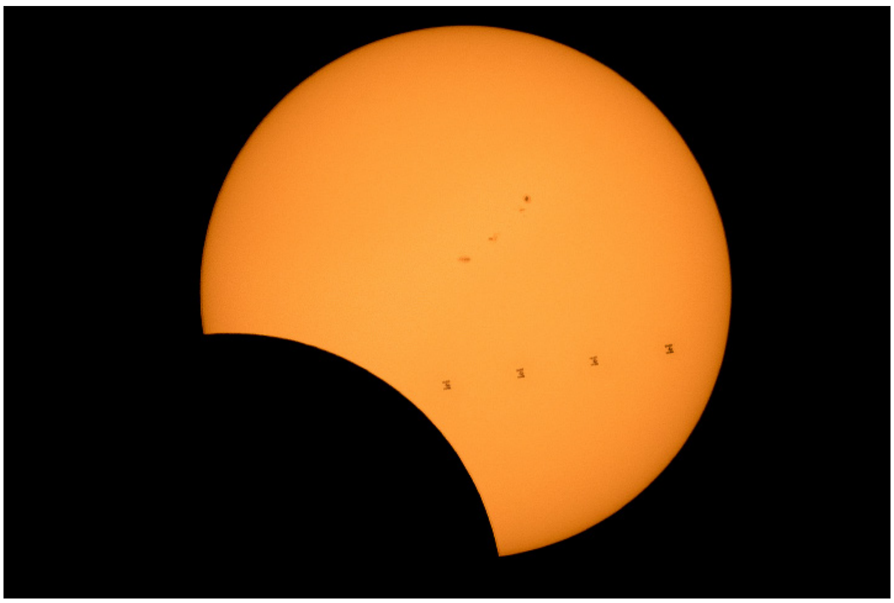
A personal view of the partial eclipse in DC, spelling out my daughter's name through a homemade pinhole projector. **Photo credit:** Heather Hanson

**A Former Astronaut Views His First Total Eclipse**

As the NASA eclipse coverage began to wind down, **Karen Fox** interviewed former NASA Astronaut **Mike Massimino** [New York's Intrepid Sea, Air & Space Museum—*Senior Adviser*] who is a veteran of two Space Shuttle flights. He described his experience viewing his first total solar eclipse. The cloud cover over Charleston notwithstanding, he thought it was a remarkable experience. He could *see* it unfold in the sky above, he could *feel* it (it got cooler!), and he experienced it with a group of energetic people—mostly students at CoC. Fox asked him to comment on his experience flying above Earth. He commented on both the beauty of Earth when viewed from above and the unceasing clockwork motion of the sun, moon, and Earth, which move together in a celestial dance that has gone on for eons and will continue for many more. He noted that we now have the ability to watch from above (e.g., previously from the Shuttle, and now from the ISS), and also saw on display during today's eclipse.

**A View from 252 Statute Miles Above**

NASA saved one of the broadest—and probably the most unique—perspectives of the eclipse for last. During the eclipse, the ISS flew 252 statute miles above Earth over Southern Canada (south of Hudson Bay). During the second of three passes during the eclipse, the moon covered 44% of the sun's surface, and the crew onboard the space station was busy taking observations of the shadow using a high-definition video camera and a number of still-image cameras. After more than three hours of NASA eclipse coverage, as the moon's shadow departed the continental U.S. and headed out over the open waters of the Atlantic, Dwayne Brown handed coverage to **Rob Navias** [NASA's Johnson Space Center (JSC)—*Public Affairs Office*] who was at Mission Control at JSC. From there, the well-known "Voice of Mission Control" interviewed four members of the *Expedition 52* crew from the Destiny Laboratory, to get their impressions of seeing an eclipse from the vantage point of ISS—see *The View from Above—Part II* on page 16 to learn more about this interview. (The photo below shows the ISS transiting the sun, captured earlier as the solar eclipse traversed over Wyoming.)



The photograph is a composite, made from seven frames, that shows the International Space Station (ISS) as it transited the sun at roughly 5 mi (~8 km) per second. It was taken on August 21, 2017, from Banner, WY. **Image credit**: NASA's Earth Observatory

*"The Earth from space is the most beautiful thing I've ever seen. It really is beyond words. It's like looking into paradise. It's just a beautiful planet. We are very lucky to be here… The beauty… and also the sense of clockwork of this ballet—this dance—that goes on between the Earth, and sun and the moon. You see that from space. You can see the rotation of the Earth, the terminator dividing night and day—and as the Earth just steadily rotates. That's what we witnessed today. The clockwork with the moon involved getting in the path of the sun. It's that clockwork that continues that still amazes me…To see [the clockwork] in space was cool, and now to see it down on Earth was cool as well."*

—**Mike Massimino** [*Former NASA Astronaut*]

## The View from Above—Part II: The International Space Station's Expedition 52 Crew Views the Total Solar Eclipse

**Rob Navias** [NASA's Johnson Space Center—*Public Affairs Office*] talked to four members of the *Expedition 52* crew:* NASA Astronauts **Peggy Whitson**, **Randolph "Randy" Bresnik**, and **Jack Fischer**; and European Space Agency Astronaut **Paolo Nespoli**. He asked each of them about their experience viewing the eclipse. What follows is a highlight from each astronaut's remarks. Navias's full interview with the ISS Expedition 52 crew comes near the end of the NASA TV broadcast (at approximately 3:20:00)—see *https://www.nasa.gov/eclipselive*.

**Whitson** has logged more hours in space than any other U.S. astronaut.** Asked to compare this experience to her long list of previous experiences in space, she said, "I think that having the privilege of being on three different long-duration missions has given me lots of interesting experiences. This is just another one to put in the history books for my memory." But she added, "I really enjoyed seeing this—and I think a little more than I expected to. And so, it's…another very special day of this fantastic experience of being in space."

**Bresnik** remarked on how far humanity has come. A few hundred years ago eclipses would catch us by surprise, but we now have the amazing ability to not only know an eclipse is coming, but to travel to be in the path of totality—and even to witness it from above! He wondered from what new vantage points humanity might look upon the 2024 eclipse.

**Fischer** commented on the huge coordination effort that was required for today's observations and credited Bresnik for organizing the observations. Like Whitson, he said that he underestimated what he would see, commenting that, "The spot was a lot darker—and a lot larger—than I thought it would be" (see image of the shadow, below).

**Nespoli** also has considerable experience in space, including a previous stint on *ISS Expedition 27* that concluded in 2011. As the Soyuz Transportnyi Modifitsirovannyi-20 (TM-20) capsule departed, he took what has become an iconic image of the Shuttle *Endeavor* linked to the ISS. He said today's experience was even more remarkable—because it was truly a team effort. More specifically, he said that he always assumed the umbra would be a "defined square;" he described what he actually saw as "kind of a smudge" that moved across Earth's limb.

The *Expedition 52* crew enjoyed a unique view of the eclipse from 252 statute miles above. The image above shows the moon's dark shadow as seen from their vantage point on the ISS. The shadow was visible near Earth's *limb*, the boundary between the atmosphere and space. The upper levels of the atmosphere faded from blue to black as many clouds lower down bubbled up and around the shadow. **Image credit**: NASA's Earth Observatory

After experiencing totality on the ground in Charleston, former Astronaut **Mike Massimino** asked the *Expedition 52* crew members: *What things do they get to experience that we don't see on the ground?* As the astronaut with the longest duration in space, Whitson answered on behalf of the group. She said that the whole experience of living in space on a daily basis is very special. The eclipse experience today was certainly memorable, but she also mentioned some recent opportunities to observe auroras, and the scientific research onboard the ISS—and of course "you can't beat the view during a spacewalk!"

* Other *Expedition 52* crew include Russian Cosmonauts Fyodor Yurchikhin and Sergey Ryazanskiy.

** Whitson and Fischer (and Cosmonaut Yurchikhin) safely returned to Earth on September 2, 2017, on a Soyuz capsule that landed in Kazakhstan.

**Conclusion**

The broadcast hosts shared some final reactions to the experience. **Yari Collado-Vega** said, "I got goosebumps." **Alex Young** was amazed by how fast the experience enveloped them. This was **Dwayne Brown's** second time experiencing a total eclipse; his first time was in Africa, but still, he said,"It's amazing. It's spiritual." Brown said it was an entirely different experience to share an eclipse on American soil with NASA colleagues. The hosts were all excited at the prospect of being able to "do it again" in 2024!

The 2017 Total Solar Eclipse is now over, but there will be other eclipses in the near future—there is, after all, one somewhere on Earth every 1.5 years. In 2019 another total solar eclipse will be visible over parts of Argentina. Then, in 2024 the U.S. gets another chance to be in the path of totality, which will track from south to north—and Carbondale, IL is in the path again! Make your plans now to be there for this "twice-in-a-decade" event—or somewhere else along the path of totality in 2024. As this author can attest, it's an experience that you will never forget! ■

*In 2024 the U.S. gets another chance to be in the path of totality, which will track from south to north—and Carbondale, IL is in the path again!*



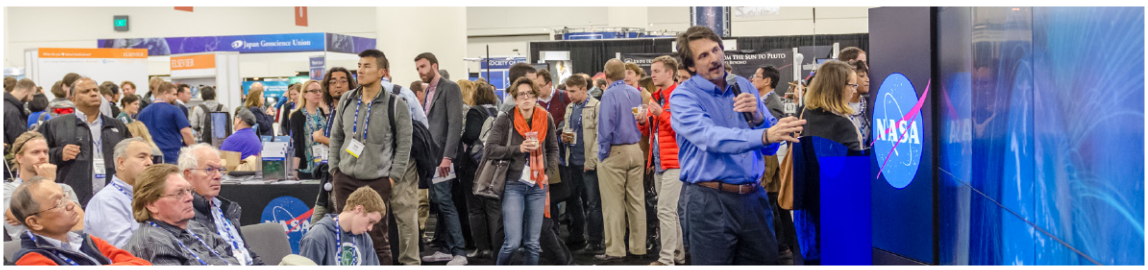
## Storytelling and More: NASA Science at the 2017 AGU Fall Meeting

Please make plans to visit the NASA booth (#1645) during the American Geophysical Union's (AGU) annual Fall Meeting—**to be held this year in New Orleans, LA!** The exhibit hall will open on Monday, December 11, and will continue through Friday, December 15.

NASA Science has many stories to tell, and the NASA exhibit will allow you to immerse yourself in them. The nine-screen Hyperwall is the focal point of the storytelling experience, where scientists will give presentations throughout the week covering a diverse range of research topics including Earth science, planetary science, and heliophysics. The exhibit will also feature a wide range of science demonstrations, printed material, and tutorials on various data tools and services.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*http://eospso.nasa.gov*—in early December.

We hope to see you in New Orleans!



A NASA Science presentation using the dynamic Hyperwall display during the 2016 AGU Fall Meeting. **Photo credit:** NASA

# Terra Flips for Science

*Tassia Owen, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., tassia.owen@nasa.gov*
*Abigail Nastan, NASA/Jet Propulsion Laboratory, abigail.m.nastan@jpl.nasa.gov*

*The last time the Terra satellite was turned to look at the moon was in 2003, although one instrument on Terra, the Moderate Resolution Imaging Spectroradiometer (MODIS) has been looking at the moon monthly for almost its entire lifetime.*

On August 5, 2017, the Terra spacecraft—the first "flagship" mission in NASA's Earth Observing System—essentially did a "backflip": The spacecraft turned away from Earth to view the moon and deep space, a *lunar maneuver*. But, why would a satellite with a mission to study Earth be pointed at the moon and deep space?

The answer comes down to calibration. "The moon is like a standard candle or lamp; the amount of energy from it is well known, so if you look at it periodically, it allows you to see if your instruments are changing over time," said **Kurt Thome** [NASA's Goddard Space Flight Center—*Terra Project Scientist*].

Lunar maneuvers are important to check the accuracy of the instruments. This not only ensures the quality of Terra's numerous science datasets, but also the reliability of other satellites and weather and climate models that use Terra's data to calibrate their own products. When Terra's instruments are accurate, weather forecasts become more accurate.

The last time the Terra satellite was turned to look at the moon was in 2003, although one instrument on Terra, the Moderate Resolution Imaging Spectroradiometer (MODIS), has been looking at the moon for almost its entire lifetime. About once a month, the spacecraft does a routine roll maneuver, where it essentially spins on its x-axis. This allows MODIS "to peek out of the corner of its view and get a view of the moon every month," explained Thome. The other instruments on Terra don't have this capability or the prime placement required to take such measurements. "For MODIS, it's been a great way to understand the instrument over its lifetime and notice any changes," Thome stated.

The recent lunar calibration maneuver gave two additional instruments on Terra, the Multi-angle Imaging Spectroradiometer (MISR)—see *MISR Angles in on the Moon* on page 19—and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on Terra—see **Figure**—their first opportunity to view the moon in 14 years.[1] "If something is really different, then we'll ask, 'is the lunar model correct?' Hopefully it will all match up. If it doesn't, then we have to figure out what is causing it," says Thome.

**Figure**. An image of the moon obtained by Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) during the lunar maneuver on August 5, 2017. ASTER's data will become increasingly accurate as a result of this look at the moon. ASTER has the highest spatial resolution of all of Terra's instruments. **Image credit**: NASA/Japanese Ministry of Economy Trade and Industry/National Institute of Advanced Industrial Science and Technology/Japan Space Systems, and U.S./Japan ASTER Science Team

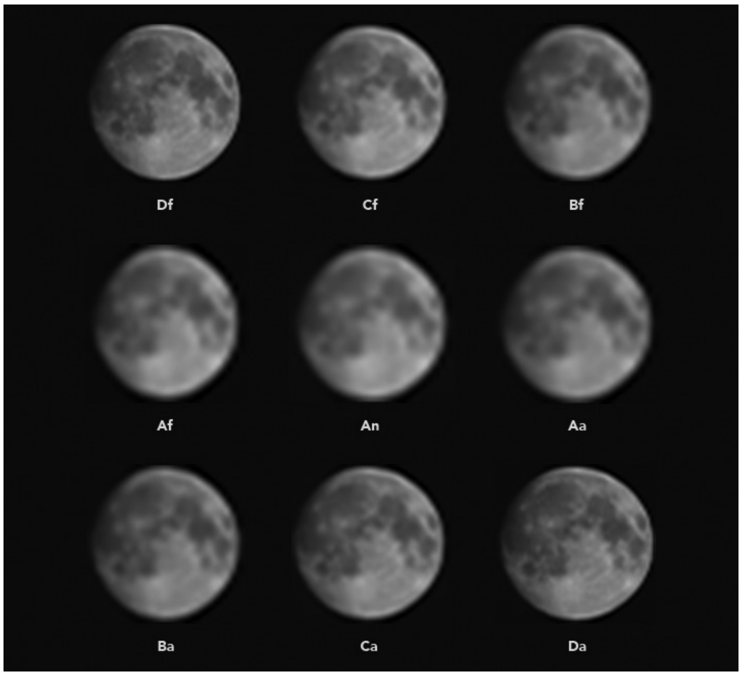
The deep space lunar calibration maneuver was executed without incident. The Terra team (pictured on page 19) worked diligently, using software that is over 17 years old, to execute all the commands to ensure that this high-risk maneuver was successful. After 17 years of collecting valuable data and with dwindling fuel supplies, Terra is nearing the end of its mission; this look at the moon was an opportunity for all of the MODIS, MISR, and ASTER instrument teams to "double check" their data one last time before the mission ends. The maneuver should help improve the calibration of these instruments, ensuring the quality of some of the longest Earth science datasets available, and allow scientists to have greater confidence in the numerous applications that rely on Terra's data.

[1] More images from the Terra Deep Space Lunar Calibration Maneuver can be found at *https://earthobservatory.nasa.gov/IOTD/view.php?id=90764&eocn=home&eoci=iotd_previous.*

## MISR Angles in on the Moon

Inherent in its name, the job of the Multiangle Imaging Spectroradiometer (MISR) instrument on NASA's Terra satellite is to view Earth from a variety of angles. For more than 17 years, its 9 cameras have stared downward 24 hours a day, faithfully collecting images used to study Earth's surface and atmosphere. On August 5, 2017, however, MISR captured some very unusual data as the Terra satellite performed a backflip in space.

One of MISR's strengths is the stability of its measurements over time, which relies on very accurate calibration. If changes in its cameras' responses to light aren't properly accounted for, the images captured by MISR would make it appear as if Earth were growing darker or lighter over time, which would throw off scientists' efforts to characterize short-term events such as air pollution and cloud cover, and longer-term phenomena related to Earth's climate. Because of this, the MISR team uses several methods to calibrate the data, all of which involve imaging something with a known (or independently measured) brightness and correcting the images to match that brightness. Every month, MISR views two panels on the instrument of a special material called Spectralon®, which reflects sunlight in a very particular way and has exquisitely known spectral characteristics. Periodically, this calibration is checked by a team who measures the brightness of a flat, uniformly colored surface on the Earth, usually a dry desert lakebed, as MISR orbits overhead. The lunar maneuver offers a third method to check the brightness calibration of MISR's images.




When viewing Earth, MISR's cameras are normally fixed at nine different angles, with one (called An) pointed straight down, four pointed forwards (Af, Bf, Cf, and Df) and four angled backwards (Aa, Ba, Ca, and Da). The A, B, C, and D cameras have different focal lengths, with the most oblique (D) cameras having the longest focal lengths in order to preserve spatial resolution on the ground. During the lunar maneuver, however, the spacecraft rotated so that each camera saw the almost-full moon straight on. This means that the different focal lengths produce images with different resolutions (notice the D cameras produce the sharpest images). These grayscale images were made using data from the red spectral band of each camera, which has the highest resolution. **Image credit**: NASA/JPL-Caltech, MISR Team

**Dimitrios Mantziaras** [GSFC—*Terra Mission Director*] reviews commands with **Andrew McVey** [GSFC—*Terra Engineer*] as the rest of the team executes the lunar maneuver. Shown in the picture are: **Jason Hendrickson**, **Ian Crum**, **Randall Allen**, **Richard Quinn**, **Thomas Kipp**, **Sean Li**, **Max Fisher**, and **Lindsai Bland**. **Photo credit**: Kurt Thome

As one of three flagship Earth-observing satellites, Terra's data are the foundation for an unmatched time series of remote sensing products. Terra's acrobatic maneuver provides another piece of that record that will allow its detailed datasets to be used well into the future. ■

# NASA Missions Working Together for Improved Atmospheric Data: ICESat-2 Convenes Joint Atmospheric Tutorial

*Sabrina Delgado Arias, NASA's Goddard Space Flight Center/Science Systems and Applications, Inc., sabrina.delgadoarias@nasa.gov*
*Molly Brown, University of Maryland, College Park, mbrown52@umd.edu*
*Steve Palm, Science Systems and Applications, Inc., NASA's Goddard Space Flight Center, stephen.p.palm@nasa.gov*
*Yuekui Yang, NASA's Goddard Space Flight Center, yuekui.yang-1@nasa.gov*
*Thomas Neumann, NASA's Goddard Space Flight Center, thomas.neumann@nasa.gov*

On May 31 and June 1, 2017, the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) Applications Team convened a Joint Atmospheric Tutorial at the Discovery Learning Bechtel Collaboratory at the University of Colorado Boulder. The tutorial was a collaboration between the ICESat-2 mission and representatives of the joint NASA and French Centre National d'Études Spatiales (CNES) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission; the International Space Station (ISS)-based Cloud-Aerosol Transport System (CATS) instrument; the joint European and Japanese Earth Clouds, Aerosols and Radiation Explorer (EarthCARE) mission; and the European Space Agency (ESA)'s Atmospheric Dynamics Mission–Aeolus (ADM-Aeolus) satellite—see **Table** on pages 21 and 22. The goal of the meeting was to increase participants' familiarity with ICESat-2 mission objectives and atmospheric data product functionalities, as well as to encourage exploratory discussion on potential for future joint-product development.

The tutorial was one of a series of prelaunch outreach events organized by the ICESat-2 Applications Program. As such, it was designed to expand awareness of planned ICESat-2 atmospheric observations, including along-track atmosphere backscatter, cloud, and other significant atmosphere layer height-related data, blowing snow, and optical depth (e.g., at the blowing snow layer and the atmosphere column). The tutorial was also designed to identify opportunities to leverage the planned data with information from other satellite instruments to maximize their utility for the applied and operational atmospheric science communities.

Prior to the meeting, the Applications Team worked in consultation with **Ute Herzfeld** [University of Colorado Boulder], **Steve Palm** [NASA's Goddard Space Flight Center (GSFC)], and **Yuekui Yang** [GSFC] to design the meeting agenda. Palm and Yang are ICESat-2 Science Definition Team members leading the development of the atmospheric data product. A web-conferencing system, used for the duration of the tutorial, allowed for remote access by participants joining from off-site locations nationally and from overseas, which included representatives from EarthCARE and ADM-Aeolus who were not able to attend the meeting in Colorado. The tutorial brought together 47 participants—19 in person and 28 via remote access. In-person participants were from NASA, University of Colorado Boulder, National Snow and Ice Data Center (NSIDC), Naval Research Laboratory (NRL), National Center for Atmospheric Research, and National Oceanic and Atmospheric Administration (NOAA)'s Earth System Research Laboratory. Remote access attendees were from the European Space Agency, the Koninklijk Nederlands Meteorologisch Instituut [KNMI; the Royal Netherlands Meteorological Institute], the Italian Consiglio Nazionale delle Ricerche [CNR; National Research Council], Environment and Climate Change Canada, NOAA's Laboratory for Satellite Altimetry, Western States Air Resources Council, NASA's Short-term Prediction Research and Transition Center, and various national and international universities seven, national; four, international.

The ICESat-2 Applications Team and **Ute Herzefeld** [University of Colorado] hosted the meeting. Herzfeld conducts research on the detection of atmospheric layers, and potential applications in climate modeling and science. She is interested in using ICESat-2 atmospheric data to derive blowing snow information and has proposed to conduct prelaunch research (as part of the ICESat-2 Early Adopter program)[1] to see if techniques developed for analysis of ICESat Geoscience Laser Altimeter System (GLAS) and CALIPSO's Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) can be extended to use with ICESat-2's Advanced Topographic Laser Altimetry System (ATLAS), to demonstrate the feasibility of using the derived blowing snow data to increase transportation (i.e., road and aviation) safety. As a cohost of the meeting, Herzfeld played a key role in facilitating the dialogue needed to understand how to best combine datasets from different missions (originated by NASA and others) with those from ICESat-2.

The tutorial introduced two programs that are part of NASA's Applied Science Program that support the application of Earth science observations for decision making: The Health and Air Quality Applied Sciences Team (*https://haqast.org*) and the Mission Applications

[1] To learn more, see "Early Adopters Prepare the Way to Use ICESat-2 Data" in the July–August 2015 issue of *The Earth Observer* [**Volume 27, Issue 4**, pp. 31-36—*https://go.nasa.gov/2xpUlIE*].

Program, including its Early Adopter Program (*https://icesat-2.gsfc.nasa.gov/early_adopters*). Representation from the NSIDC Distributed Active Archive Center (DAAC),[2] where ICESat-2 data will be archived, allowed participants to learn about the personalized support for data selection, access, and usage that the DAAC is developing for the mission. The tutorial also allowed the DAAC to gather feedback from participants on visualization of vertical profiles, three-dimensional (3D) point cloud visualization, and needs for data access, tools, and services. Participants were also enthusiastic about the live demonstration by the DAAC on Earthdata Search[3] and exploration of imagery using Worldview Applications (*https://worldview.earthdata.nasa.gov*).

This article provides a brief introduction to the ICESat-2, CALIPSO, CATS, EarthCARE, and Aeolus mission objectives and their respective atmospheric data products, followed by a synthesis of the outcomes and a summary of participant feedback from the tutorial.

[2] The DAACs are among the topics discussed in "Earth Science Data Operations: Acquiring, Distributing, and Delivering NASA Data for the Benefit of Society" in the March–April 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 2**, pp. 4-18—*https://go.nasa.gov/2h2O7YR*].

[3] Earthdata Search allows one to search, discover, visualize, refine, and access NASA Earth Observation data. For more information, visit *https://search.earthdata.nasa.gov/search*.

**Table.** Atmospheric Lidar Instrument Technical Specifications [Mission listed in brackets.]

| **Advanced Topographic Laser Altimetry System (ATLAS)**<br>[Ice, Clouds, and Land Elevation Satellite-2 (ICESat-2)] | |
|---|---|
| Measurement Concept | Single photon counting lidar |
| Wavelength | 532 nm |
| Beams | Multibeam 3 pairs; 6 total |
| Orbit | 500 km mean altitude; polar, non-sun-synchronous; 92° inclination |
| Pulse Repetition Rate | 25 Hz [400 shot aggregation, 280-m along-track resolution, binned at 30-m vertical resolution (467 bins total)] |
| URL | *https://icesat-2.gsfc.nasa.gov* |
| ATLAS will be the sole instrument on ICESat-2, which is scheduled for launch in 2018. ICESat-2 has four science objectives for ice sheets, sea ice, and vegetation, which drive its design. While ATLAS has no specific overall mission requirements for atmospheric science, as a global satellite mission, ICESat-2 will collect data over all of Earth's surfaces. Therefore, in addition to the sea ice, land ice, and vegetation data products, the ICESat-2 mission is also developing products for ocean, atmosphere, and inland water. | |
| **Atmospheric Lidar (ATLID)**<br>[Earth Cloud Aerosol and Radiation Explorer (EarthCARE)] | |
| Measurement Concept | High spectral resolution lidar with depolarization |
| Wavelength | 355 nm |
| Beams | Single |
| Orbit | 400 km mean altitude; polar, sun-synchronous; 97.05° inclination |
| Pulse Repetition Rate | 38 Hz (2-pulse summation, 285-m horizontal resolution, 103-m vertical resolution) |
| URL | *https://earth.esa.int/web/guest/missions/esa-future-missions/earthcare*<br>*http://global.jaxa.jp/projects/sat/earthcare* |
| ATLID is one of four instruments on EarthCARE, which is scheduled for launch in 2019. Compared to CALIPSO, ATLID is expected to provide improved daylight performance, direct measurement of aerosol extinction, and measurement of extinction-to-backscatter ratios. | |
| **Atmospheric LAser Doppler INstrument (ALADIN)**<br>[Atmospheric Dynamics Mission (ADM) Aeolus] | |
| Measurement Concept | Direct detection ultraviolet Doppler wind lidar |
| Wavelength | 355 nm |
| Beams | Emits circularly polarized light |
| Orbit | ~320 km mean altitude; off-nadir, sun-synchronous; 96.97° inclination |

**Table.** Atmospheric Lidar Instrument Technical Specifications [Mission listed in brackets] (continued).

| | | |
|---|---|---|
| Pulse Repetition Rate | 50 Hz (2 receiver channels (one for Rayleigh and the other for Mie scattering) each sampling the wind in 24 vertical bins. 0.25 to 2 km vertical resolution of layer-average winds; altitude range up to about 30 km) | |
| URL | *http://esamultimedia.esa.int/docs/EarthObservation/AEOLUS_sheet_170809.pdf* | |
| ALADIN is the single instrument that will be carried by the Aeolus satellite (target launch January 2018) and will be the first Doppler wind lidar in space. Aeolus-ALADIN will address the lack of homogenous global coverage of direct wind profile measurements producing horizontally projected line-of-sight wind profiles both in clear and (partly) cloudy conditions down to optically thick clouds. Aeolus measurements will be delivered in near-real-time (within 3 hours) and could benefit numerical weather prediction and aerosol assimilation in forecast and climate models. | | |
| **Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP)** [Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)] | | |
| Measurement Concept | Two-wavelength polarization-sensitive Lidar | |
| Wavelength | 532 nm and 1064 nm | |
| Beams | Emits circularly polarized light | |
| Orbit | 705 km mean altitude; off-nadir, sun-synchronous; 98.2° inclination | |
| Pulse Repetition Rate | 20.25 Hz (333-m horizontal resolution; 30-m below 8.5 km to 60-m above 8.2-km vertical resolution) | |
| URL | *https://www-calipso.larc.nasa.gov* | |
| CALIOP's polarization lidar is one of three instruments on CALIPSO, which has been in orbit since 2006. It has two wavelengths that allow for detection of clouds, aerosols, and surfaces (the 1064-nm wavelength is used only when measuring aerosols). CALIOP has provided data that have enabled the creation of a global, multiyear data-set for improved visualization of Earth's atmosphere to advance understanding of the role of aerosols and clouds in the climate system. | | |
| **Cloud–Aerosol Transport System (CATS)** International Space Station | | |
| Measurement Concept | Photon-counting ISS lidar with depolarization | |
| Wavelength | **Mode 1 (February 10–March 21, 2015)** | **Mode 2 (Mar 25, 2015–present)** |
| | Backscatter: 532 and 1064 nm | Backscatter: 532 and 1064 nm |
| | Depolarization: 532 and 1064 nm | Depolarization: 1064 nm |
| | Level-2 Products: 532 and 1064 nm | Level-2 Products: 1064 nm |
| Beams | **Mode 1** | **Mode 2** |
| | Multibeam | Laser 2 |
| Orbit | ~415 km mean altitude, 51° inclination | |
| Pulse Repetition Rate | 4- and 5-kHz lasers (350-m horizontal resolution, 60-m vertical resolution) | |
| URL | *https://cats.gsfc.nasa.gov* | |
| CATS, launched in 2015, was installed on the Japanese Experiment Module–Exposed Facility on the International Space Station. It is a lidar designed to, among other goals, complement the CALIPSO data record with diurnally varying cloud and aerosol vertical profiles. It is also used to monitor dynamic events such as wildfires and volcanic eruptions. CATS data products provide comprehensive coverage of the tropics and midlatitudes, which are considered the primary aerosol transport paths. CATS can detect the full extent of aerosol plumes and distinguishes clouds embedded in aerosol layers. Near-real-time data products are created within six hours of data acquisition. | | |

**Outcomes**

One of the main questions addressed during the meeting was the potential synergy arising from overlap of each of the other instruments characteristics with those of ICESat-2. **Figure 1** summarizes the expected lifetime for each mission or investigation. ICESat-2 is expected to at least partially overlap with the operation of ADM/Aeolus and EarthCARE, during the 2018 to 2022 period. Overlap between ICESat-2 and CALIPSO

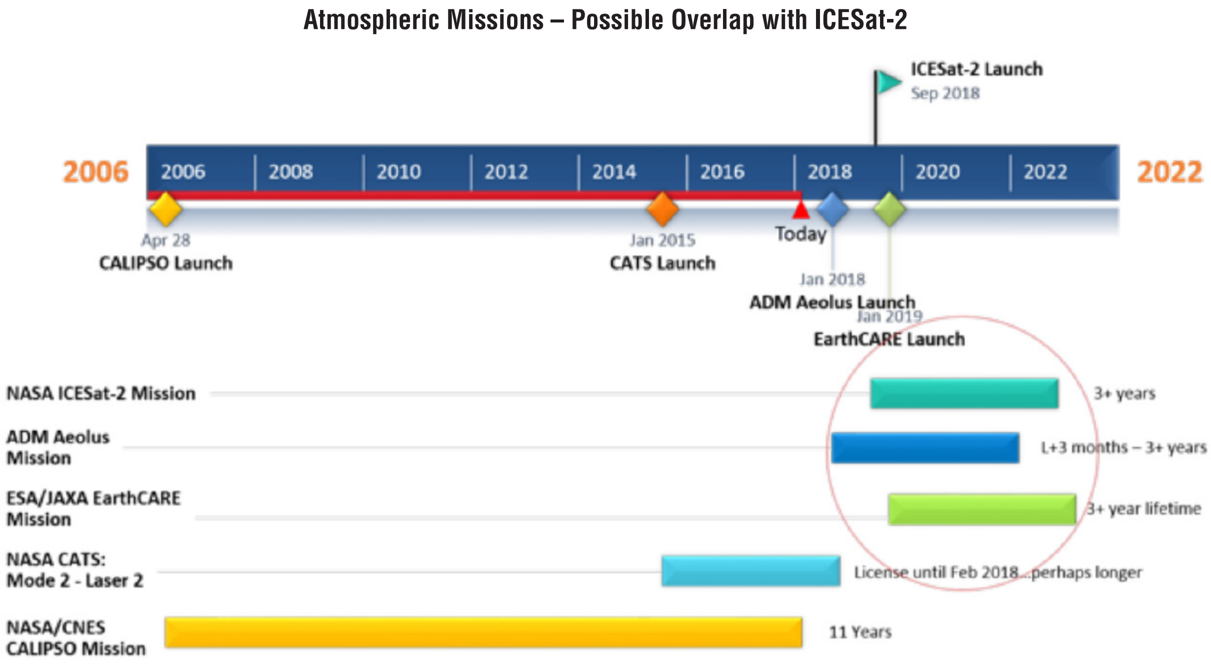



**Figure 1.** The bar chart shows the current projected timetables for the missions discussed in this article. The circle shows the area of possible overlap with ICESat-2. **Image credit:** Sabrina Delgado Arias

and CATS is a bit more dubious: CALIPSO is already well beyond its projected mission lifetime and CATS has license to operate through February 2018, perhaps longer (it had a six-month requirement and three-year goal). There is, however, a possibility of a CATS "follow-on" mission (that would be known as CATS-I), which has been submitted in response to an Earth Venture Instrument-3 Announcement of Opportunity.[4] Nevertheless, discussion on complimentary measurements during the meeting encompassed all instruments.

**What to Expect from the ICESat-2 Atmospheric Data Products**

One of the primary goals of the tutorial was expectation management, which was provided by the Science Definition Team members who provided a thorough description of ICESat-2's strengths and limitations with respect to the atmospheric data:

*Strengths*

- *Excellent nighttime data*. ATLAS should do an excellent job detecting thin clouds at night—down to an optical depth of approximately 0.05.
- *Continuation of measurements.* ICESat-2 will continue the cloud, aerosol, and blowing-snow measurements begun by ICESat and continued by CALIPSO.
- *Orbit.* ICESat-2 will operate in a 92° inclination orbit, providing data from polar areas not surveyed by other existing or planned missions.

*Limitations*

- *Limited cloud detection during peak sunlight.* Solar background noise is expected to reach up to 10 MHz due to the design of ATLAS's receiver optics and electronics. Cloud detection will be limited to an optical depth of approximately 0.5.
- *Limited vertical range*. The atmospheric data products will span the range from 13.5 km (~8.4 mi) above the surface to 0.5 km (~0.3 mi) below the surface. Other sensors designed for cloud studies typically have a wider range; for example, CALIPSO's data span from the surface to 26 km (~16 mi) above the surface.
- *Folding effect.* The pulse repetition frequency of ATLAS is 10 kHz, which results in consecutive laser pulses being separated in flight by ~30 km (~19 mi). As a result, reflections for the Earth's surface arrive at ATLAS at the same time as returns from clouds 15 km (~9 mi) above the surface (from the next laser pulse). Consequently, a cloud layer detected at 2 km (~1.2 mi) altitude could actually be at 17 km (~10.6 mi) altitude. See **Figure 2** for an explanation of this phenomenon.
- *45-day latency.* Measurements of along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth, will be available every 45 days.

[4] The Earth Venture (EV) class of missions is a series of uncoupled, relatively low-to-moderate cost, small- to medium-sized, competitively selected missions that includes three classifications: full orbital missions (EVM), instruments for orbital missions of opportunity (EVI), and suborbital projects (EVS).

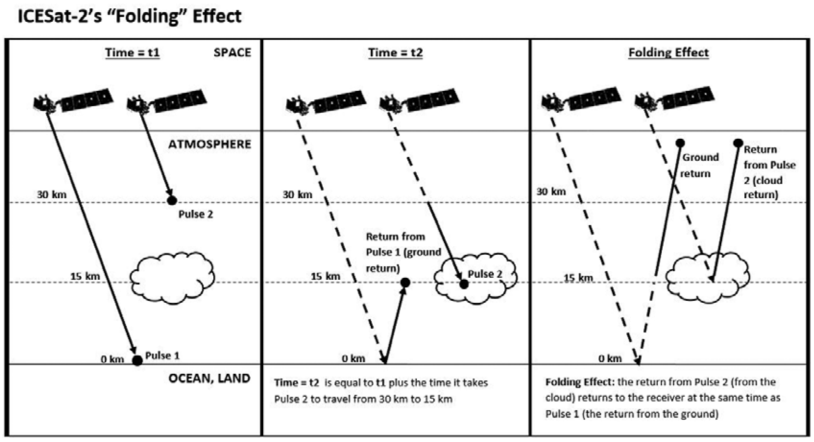



**Figure 2.** *ICESat-2's folding effect***.** At time *t1*, two successive laser pulses are shown. Pulse 1 has just reached the ground while Pulse 2 is at 30-km (~38-mi) altitude. At time *t2,* the return signal from the ground reaches 15-km (~19 mi) altitude on its way back to the receiver. At the same time, the next laser pulse (Pulse 2) has travelled downward to 15 km. The return from Pulse 2 (either from a cloud or aerosol) will travel back to the receiver and arrive at the same time as the ground return from Pulse 1. Thus, what is recorded by the ATLAS instrument is the sum of the scattering at 15 km and 0 km (i.e., the ground). This effect, called *folding*, occurs in the same way for all altitudes within the 15-km ATLAS profile. **Image credit:** Sabrina Delgado Arias, Stephen Palm

## Ideas for Overcoming ICESat-2's Limitations

Clarification of ICESat-2's limitations spurred discussion on how to work together to find solutions for better atmospheric data products. Among the recommendations were joint aerosol studies, sharing data and data-development experiences, and looking for algorithm synergies. Participants emphasized the need to develop a product to minimize ICESat-2's large signal-to-noise differences between night and day data, which will make it hard to conduct studies comparing diurnal differences in cloud properties. Participants also recommended further research into methods for noise reduction to improve the usability of the daytime data.

Participants recommended using both EarthCARE and CALIPSO data to help address ICESat-2's folding effect. For example, when ICESat-2 and EarthCARE are aligned closely in space and time, measurements from EarthCARE's ATLID can be used to help validate those from ICESat-2's ATLAS, and possibly help understand the folding problem. Similar synergy might be achieved with CALIPSO's CALIOP and ICESat-2's ATLAS.

**Lucia Mona** [CNR's Institute of Methodologies for Environmental Analysis] also suggested exploring the folding—or *pulse-aliasing*—solution her team developed to create a flag in the ATLAS Atmosphere Cloud Layer Characteristics [ATL09] data product for ICESat-2. Mona is an Early Adopter for the mission and as such has been conducting prelaunch research to demonstrate ICESat-2's capability of providing vertical profiles for the aerosol backscatter coefficient and to define its potentialities and limits.

There were also several ideas for other joint studies to improve the ICESat-2 atmospheric retrievals, including calibrating aerosol and cloud statistics in polar regions; using Afternoon Constellation, or "A-Train,"[5] image patterns and research approaches for classifying aerosols, exploring algorithm synergies with CATS, and looking at how CATS and ICESat-2 cloud climatological characteristics change over the tropics. A synergetic study of blowing snow radiative properties was also proposed.

**Janet Intrieri** [NOAA's Earth System Research Laboratory] described the potential for using ICESat-2 within NOAA's coupled ice-ocean-atmosphere forecast model—the Regional Arctic System Model-Earth System Research Laboratory (RASM-ESRL). While the primary interest is to use the sea ice thickness derived from ICESat-2 for model initialization and to compare forecasts of ice properties (e.g., ice thickness comparisons), RASM-ESRL model development could provide ICESat-2 with snow product guidance and vertical cloud property information.

Another topic of discussion was latency requirements. For example, the NRL currently ingests CALIPSO observations of aerosol and dust plumes in its aerosol transport model. These observations are required within 12 hours of real time. However, most data users do not require such a fast turnaround. Further discussion is needed to understand possible approaches or solutions to ingesting ICESat-2 data, operationally.

[5] *The Afternoon Constellation*, or "A-Train," consists of 8 U.S. and international Earth science satellites, including CALIPSO, that fly within thirteen minutes of each other to enable concurrent science. To learn more, refer to "The Third A-Train Symposium: Summary and Perspectives on a Decade of Constellation-Based Earth Observations" in the July–August 2017 issue of *The Earth Observer* [**Volume 29, Issue 4,** pp. 4-18—*https://go.nasa.gov/2wcckpR*].

**Potential ICESat-2 Contributions to Other Missions**

There was also discussion about how ICESat-2 could benefit other missions. For example, ICESat-2's attenuated backscatter profiles could be a good test of EarthCARE extinction retrievals and determining cloud and aerosol types. CATS could benefit from the ideas on how to fix some problems shared with ICESat-2—for example, the folding effect. Participants were enthusiastic about the idea of having ICESat-2 periodically point to NASA's Micro-Pulse Lidar Network (MPLNET) sites for calibration (*https://mplnet.gsfc.nasa.gov*). This may be important, as calibration/validation activities are not funded for ICESat-2 atmosphere data products.

**Potential Applications for ICESat-2 Data**

Communication of the expected benefits and limitations of the ICESat-2 atmospheric data was important to help establish potential opportunities and barriers for utilization of various applications. During the meeting, discussion centered on three potential applications—air quality prediction, weather forecasting and climate monitoring, and monitoring wildfires—that could benefit from ICESat-2 alone or in combination with other mission datasets.

*Air Quality Prediction*

ICESat-2 could be used to improve the accuracy of air quality prediction without providing information about atmospheric constituents or chemical composition. ICESat-2 will provide vertical profiles of attenuated backscatter, which is related to aerosol loading and pollution content, and may be able to provide information on the planetary boundary layer height. There was discussion about the benefits of complementing ICESat-2 with other datasets. For example, ICESat-2 and CALIPSO data might be used together to provide constraints on the vertical distribution of aerosols; the combination might also be useful for improving the temporal and spatial coverage of aerosol data in polar regions. ICESat-2 vertical profiles could build upon current work with CALIPSO data to assess air quality above the ground, to help track the vertical movement of smoke in plumes emitted by fires.

*Weather Forecasting and Climate Monitoring*

ICESat-2 also could be used to provide a consistent and refined annual climatology of clouds. Discussion focused mainly on the polar regions, where there is a significant lack of data. NRL, for example, emphasized a significant lack of CALIOP information at polar latitudes, owing to its orbit in the A-Train and signal-to-noise issues, and highlighted the prospect of using ICESat-2 to fill in this polar data gap and to provide critical measurements of cirrus cloud physical properties and their occurrence. Other ideas included using ICESat-2 data to extend the CloudSat–CALIPSO observations of clouds, in particular, to supercooled liquid clouds poleward of 82˚; using ICESat-2 to detect Asian dust (more difficult to detect than Saharan dust because it is typically injected higher in the atmosphere and is more diffuse, both vertically and horizontally); and to detect volcanic ash.

*Monitoring Wildfires*

ICESat-2 also could be used to monitor smoke aerosols. The NRL, for example, suggested using ICESat-2 data in a manner similar to what is currently done with CALIPSO data, to monitor pyrocumulonimbus (pyroCb) smoke in the upper troposphere/lower stratosphere (UTLS). ICESat-2 would help in distinguishing smoke aerosols from clouds, observing the vertical characteristics of pyroCb smoke plumes, confirming pyroCb occurrence, tracking smoke transport and UTLS lifetime, and calculating aerosol mass.

**Takeaway Messages**

Fruitful discussions were conducted on the strengths and weaknesses of the ICESat-2 atmospheric products. It was pointed out that even with the folding effect and high solar background noise levels, ICESat-2 atmosphere data can significantly complement observations from other sensors. With a 92° orbital inclination, ICESat-2 covers much of Earth's higher-latitude regions, compared to CALIPSO (which has a 98.2° inclination), CATS (51.6° inclination), and EarthCARE (97° inclination). ICESat-2 will provide information through the atmospheric column (to 14.5 km above the surface) in addition to the detailed surface elevation, whereas other sensors usually only have information on the atmospheric column.

It is unlikely that CALIPSO or CATS will be in operation while ICESat-2 is collecting data, although it is not impossible. ADM-AEOLUS and EarthCARE, on the other hand, are scheduled to launch in 2018 and 2019, respectively, should be operating at the same time as ICESat-2, and will be valuable for validation and comparison through periodic cross overs between these three sensors when we will have temporally and spatially coincident data. Both EarthCARE and ADM-AEOLUS are sun-synchronous and the orbit of ICESat-2 will precess through these orbits at intervals that have yet to be determined. When this happens, the data from EarthCARE and or ADM-AEOLUS can be used to compare and potentially validate the data from ICESat-2.

The main benefit of ICESat-2's atmospheric data will be to provide continuity for the cloud, aerosol, and blowing snow measurements begun by ICESat and later acquired by CALIPSO. Even though ICESat-2 will not have CALIPSO's full capability, it will still enable

continued on page 30

# Second Surface Water and Ocean Topography Science Team Meeting

*Annette deCharon, ODYSEA LLC, adecharon@gmail.com*
*Carla Lauter, ODYSEA LLC, carla@odyseallc.com*

## Introduction

The second Surface Water and Ocean Topography (SWOT) Science Team Meeting was held in Toulouse, France, June 26-28, 2017.[1] The meeting was immediately followed by the SWOT Calibration/Validation Workshop, which took place on June 29. The meeting was planned and convened by the mission's science leads: **Tamlin Pavelsky** [University of North Carolina, Chapel Hill] and **Jean-François Cretaux** [Centre National de la Recherche Scientifique/Laboratoire d'Études en Géophysique et Océanographie Spatiales, France] for hydrology, and **Rosemary Morrow** [Centre National d'Études Spatiales (CNES), French Space Agency] and **Lee-Lueng Fu** [NASA/Jet Propulsion Laboratory (JPL)] for oceanography.

SWOT is designed to make the first-ever global survey of Earth's surface water. SWOT will provide essential information on large rivers, lakes, and reservoirs—along with high-resolution measurements of our global ocean—on average twice every 21 days. Its data will aid in freshwater management worldwide while improving ocean circulation models and predictions of weather and climate. NASA and CNES are jointly developing and managing SWOT, with contributions from the Canadian Space Agency and the United Kingdom Space Agency. Now in Phase C of its Mission Life Cycle (final design and fabrication), all major mission elements (flight, ground, system) are heading towards the project's Critical Design Review (CDR) in early 2018. In November 2016 NASA selected Space Exploration Technologies (SpaceX) of Hawthorne, CA, to provide launch services for SWOT. Launch is targeted for April 2021 on a SpaceX Falcon 9 rocket from Vandenberg Air Force Base in California.

The second SWOT Science Team Meeting lasted three days to accommodate the contributions of 160 participants, 90 oral presentations, and 38 posters. This report summarizes the big picture ideas discussed at the meeting; all of the individual presentations from the plenary, splinter, and poster sessions, are available from the SWOT website at *https://swot.jpl.nasa.gov*.

[1] For a summary of the first meeting, which includes useful general background on the SWOT mission, please reference "The Surface Water and Ocean Topography Science Team Meeting" in the September–October 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 5**, pp. 18-23—*https://go.nasa.gov/2g8tqxE*].

## Getting Ready for SWOT

With launch approaching, it is important for SWOT to engage and grow its user community. Towards this end, simulated data products will continue to be developed and improved for user training purposes. In addition, based on input from stakeholders who attended the workshop, *Engaging the User Community for Advancing Societal Application of SWOT*[2] (at the U.S. Geological Survey, April 4-6, 2017 in Reston, VA), the project is assessing the development of specific data products with short latency (i.e., two-to-three days). These *short-term* or *quick-look* products would have lower performance than SWOT's nominal science and research products, which will be released within 60 days of data acquisition.

Major activities of the SWOT Calibration/Validation Team include collecting ground-truth data using various support instruments (e.g., *in situ* sensors; aircraft-mounted interferometer, AirSWOT, for hydrology; Modular Aerial Sensing System lidar for oceanography). The SWOT Calibration/Validation Plan, scheduled for final release prior to the project's CDR, will identify key calibration parameters and approaches for their estimation; validation approaches for both key error-budget terms[3] and science products; and instrumentation for specific sites. Prelaunch field campaigns for hydrology have begun in North America and France, with plans to expand to South America, Africa, Asia, and other European sites.

## Oceanography: From "Noise" to Signal

The SWOT mission builds upon the capabilities of the *Jason series* (which includes Jason-1, launched in 2001 and decommissioned in 2013, the Ocean Surface Topography Mission (OSTM)/Jason-2, launched in 2008, and Jason-3, launched in 2016). Data from these three missions have contributed to a satellite ocean altimetry data record that began with the launch of the U.S./French Ocean Topography Experiment (TOPEX)/Poseidon satellite in 1992. SWOT's $K_a$-band Radar Interferometer (KaRIn)—shown in **Figure 1** on the next page—will have increased spatial resolution as

[2] The second SWOT Applications User Workshop report is available at *https://swot.oceansciences.org/meetings.htm?id=19*.
[3] Details about the SWOT project, mission performance, and error budget are available at *https://swot.oceansciences.org/documents.htm*.

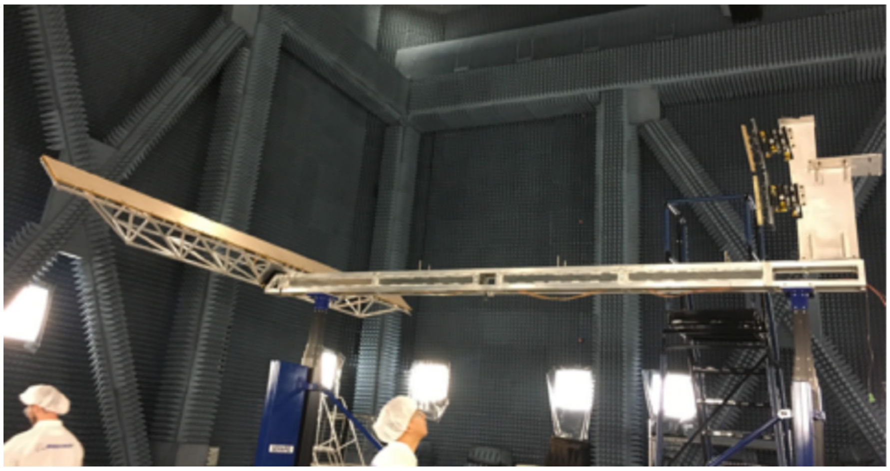


**Figure 1.** [*Left to right*] Antenna structure, boom, and $K_a$-band Radar Interferometer (KaRIn) in a NASA/JPL clean room. Using two antennas separated by 10 m (32.8 ft), KaRIn's synthetic aperture radar (SAR) data will be processed into sets of *interferograms* (i.e., amplitude, phase, coherence) to determine the elevation of water surfaces. **Photo credit:** JPL

compared to the altimeter that has flown on the Jason series—see **Table 1** for comparison. This will provide a significant opportunity to study ocean dynamics at scales previously undetectable by satellite altimeters.

SWOT will provide global observations of small *mesoscale eddies* (ubiquitous, relatively short-lived, swirling currents) and *fronts* (boundaries between two distinct water masses) at wavelengths of 15 to 200 km (9.3 to 124.3 mi). These dynamical scales are poorly observed today, but are important for their impact on horizontal and vertical currents in the ocean; in the transport of heat, carbon and nutrients; and to understand the ocean's energy budget and dissipation.

SWOT will also detect *internal waves* (IW), i.e., *gravity waves*[4] that propagate within the ocean rather than on its surface, at scales similar to the smaller mesoscale eddies. Thus, many science team members are focusing their efforts on understanding sea surface height (SSH) variability at these scales. For example, *in situ* observations from deep-ocean moorings and gliders—in conjunction with ocean general circulation models—are providing information on IW signals and ocean eddies for SWOT calibration/validation planning and data-product development. Other investigators are looking at various types of satellite data—e.g., sea surface temperature, salinity, and synthetic aperture radar (SAR)—to characterize the impact of IWs on SSH at small scales.

*Internal tides* (IT)—internal waves at a tidal frequency—can contribute several centimeters to the SSH signature and thus need to be corrected in SWOT data to distinguish other features (e.g., ocean eddies). With wavelengths ranging between 50 and 250 km (~31 and 155 mi), IT are generated in the ocean interior as surface tides move stratified water along sloping topography such as mid-ocean ridges and continental slopes. Several IT models, including those of Science Team members **Brian Arbic** [University of Michigan], **Richard Ray** [NASA's Goddard Space Flight Center], and **Edward Zaron** [Portland State University] are being analyzed to provide an initial correction for SWOT. Moreover, SWOT's IT data themselves may provide information on changes in ocean heat content over time, as has been demonstrated with altimeter-derived IT data.

Understanding how to accurately model IW and IT in ocean general circulation models (e.g., HYCOM,[5]

[4] In this context, gravity waves are waves that propagate at the interface between the atmosphere and the ocean as the force of gravity or buoyancy tries to restore equilibrium.

[5] HYCOM stands for HYbrid Coordinate Ocean Model. The HYCOM consortium is a multi-institutional effort sponsored by the National Ocean Partnership Program (NOPP), as part of the U.S. Global Ocean Data Assimilation Experiment (GODAE). Learn more at *https://hycom.org*.

**Table 1.** Comparison of Jason series and SWOT mission characteristics.

| | Jason series | SWOT |
|---|---|---|
| **Altitude** | 1336 km | 891 km |
| **Orbit Type** | 10-day repeat | 21-day repeat |
| **Inclination** | 66° | 77.6° |
| **Swath** | N/A | 120 km |
| **Frequency** | $K_u$-band | $K_a$-band |
| **Height Precision** | 2 cm @ 6 km (Jason-3) | 0.4 cm @ 6x6 km$^2$ |
| **Spatial Resolution** | 6.2 km, along track; 300 km, cross track | <100 m, imaging |
| **Instrument** | Nadir altimeter | Nadir altimeter and interferometer |

MITcgm[6]) will be key to revealing dynamics at scales from 10 to 200 km (~6 to 124 mi) in SWOT data. Of particular interest are mesoscale eddies (defined above) for which SWOT will provide more information than conventional altimeters (e.g., Jason-2 and Jason-3). Mesoscale eddies have been shown to move around as much ocean water as wind or deep-water currents, as demonstrated[7] by SWOT investigator **Bo Qiu** [University of Hawaii at Manoa].

Some SWOT Science Team members are investigating ocean features such as surface currents and fronts at even finer scales [< 20 km (< ~12 mi)]. These studies use data from multiple sources including the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging SpectroRadiometer (MISR) on Terra, the MEdium Resolution Imaging Spectrometer (formerly on the European Space Agency's Envisat), and other airborne instruments (e.g., DopplerScatt). Overall, these studies show promising results in terms of resolving the fine-scale ocean features that drive vertical currents, transporting heat up and down the water column.

SWOT's collection of high-resolution data—acquired to differentiate among internal and surface waves, tides and internal tides, eddies, and fronts—will provide additional value for oceanography studies. A related challenge, however, will be managing and distributing such large volumes of oceanographic data. In preparation, sample oceanographic data products based on simulations—and prototype user software—will be generated for testing by the community before the third SWOT Science Team Meeting in 2018. In parallel, significant efforts are underway to assess the impact of SWOT data assimilation into regional ocean analysis and forecasting systems such as France's *Mercator Ocean* (*https://www.mercator-ocean.fr/en*).

[6] MITgcm stands for the Massachusetts Institute of Technology's General Circulation Model, which is a numerical model designed for study of the atmosphere, ocean, and climate. Learn more at *http://mitgcm.org*.

[7] The abstract is at *http://science.sciencemag.org/content/early/2014/06/25/science.1252418*. American Association for the Advancement of Science subscribers may view the full article.

**Hydrology: Going With the Flow**

Given that SWOT will provide NASA's first-ever global survey of land-based water levels from satellite, the project's hydrology team has focused on defining processes to create hydrological data products. The term *pixel cloud* is used to describe how interferometric phase data will be processed into vector products to compute mean water heights, slopes, and area based on the shapes of rivers and lakes. Pixel cloud data consist of georeferenced interferogram pixels with latitude, longitude, height, classifications, and flags, thus serving as a *water mask* for SWOT.

Prior to and after launch, SWOT river data products will be constructed by attaching the pixel cloud to a *centerline*, which is fixed from pass to pass, but may be updated annually—see **Figure 2**. *Node locations* are defined at regular intervals [e.g., every 200 m (~656 ft)] along the centerline. The average length of *reaches*—sections of rivers along which there are similar hydrologic conditions, such as discharge, depth, area, and slope—are computed from nodes. Some example node and reach data are currently being distributed as shapefiles, maximizing the ease of bringing SWOT-like data into processing programs such as *ArcGIS* or *Google Earth*. Official hydrology test products will begin production in mid-to-late 2018.

In addition, geolocated, pixel-based (i.e., raster) data products are being developed to provide SWOT height and inundation-extent data, along with appropriate errors and flags, resampled onto a uniform grid. This will provide a means to study complex flow environments not effectively captured by other SWOT data products (e.g., wetlands, estuaries). Raster data products will also measure internal variability in river reaches and

**Figure 2.** [*Left*] Aerial view of a river with SWOT centerline in red. [*Right*] Blue circles show example *node locations* defined at fixed intervals along the centerline. See text for more details. **Image credit:** Michael Durand [Ohio State University]

lakes not captured by the vector products. The raster product will be available for all locations that the pixel cloud is produced.

The Discharge Algorithm Working Group is responsible for estimating river discharge from SWOT measurements. They have made excellent progress by accumulating about 40 community datasets, based on the "Pepsi Challenge"[8] and other experiments. Key challenges that still need to be addressed include standardizing assessment of algorithms and reporting uncertainty.

SWOT water detection will rely heavily on distinguishing land versus water pixels, which is challenging due to *speckle noise*[9] and variable water/land contrast as well as the near-nadir radar look angle. A *prior water probability map* is being developed for use in several processing steps, such as for definition of zones within the pixel cloud (e.g., always include floodplains and wetlands while excluding areas where the presence of water is very unlikely). Another challenge for SWOT is mitigating the impact of *dark water*, which can be caused by calm water, signal attenuation due to rain, vegetation, and low signal-to-noise ratios in some parts of the swath. The project is currently testing a dark-water flag algorithm based on an analysis of 30 years of Landsat data. Likewise, the SWOT Project is developing strategies for mitigating radar geometric distortion effects (e.g., flagging, theoretical models, simulation). An example of when such strategies might be helpful is when analyzing radar returns from higher terrain adjacent to rivers or from lakes that appear to overlay water pixels.

Accessible and accurate *a priori* lake, river, and geoid data will be key to SWOT's success. To accommodate this requirement, the Project is creating an easily used database that allows users to search and retrieve information by lake name. Several SWOT investigators are analyzing the applicability of existing lake and river datasets for use with SWOT. For example, **Tamlin Pavelsky** has created a database to support SWOT river vector data products, consisting of a combination of Landsat-derived centerlines, Shuttle Radar Topography Mission-derived drainage areas, and modeled mean river discharge. It has been used to generate continental-scale statistical estimates for SWOT. These statistics do not include rivers north of 60° N outside of Europe—since no suitable digital elevation models exist for these areas. Analysis shows that, for river reaches with minimum widths of 100 m (~328 ft) that are sampled by two SWOT passes every 21 days, data will be collected globally along 327,843 km (203,712 mi) of river length. By decreasing the minimum river reach width by half [i.e., to 50 m (164 ft)], the total length of rivers sampled by SWOT twice every 21 days increases to 663,984 km (412,580 mi), which is equivalent to 95 times the length of the Amazon River.

A large-scale simulator is being used to generate SWOT-like pixel cloud files for hydrologic modeling purposes. Some investigators are conducting experiments with theoretical SWOT observations to construct basin-wide river discharge estimations while others are developing frameworks for assimilating SWOT's global water surface elevations into hydrodynamic models.

Recently converted to open source software, the *RiverObs* package from JPL takes in pixel cloud data from the SWOT Hydrology Simulator to estimate key parameters such as water slope and height. *RiverObs* has been used to estimate discharge for the Po and Sacramento Rivers (in Italy and California in the U.S., respectively) with promising results—emphasizing SWOT's potential application to estimate discharge for rivers without gauges. A similar computing challenge still exists for determining lake volume (i.e., developing *LakeObs*); however, a general lack of bathymetry data necessitates that SWOT software developers focus on approximating lake water storage volume change over time.

**Wrap Up and Summary**

The final session began with reports on tides and currents in estuarine, coastal, and shelf environments (e.g., U.S., France, Canada, Brazil, and Southeast Asia) using *in situ*, model, and simulated SWOT water-level data. Anticipated outcomes of these studies include using SWOT to better understand river plume transport and to determine the potential impact of storm surges, among others. A number of presentations described unique applications of SWOT data to study the cryosphere, such as the feasibility of retrieving *sea ice freeboard*—the height of ice above the local sea surface—and thickness, along with the prospective ability to infer properties of ice-sheet beds and seasonal ice streams in Greenland and Antarctica. The meeting concluded with a presentation on the importance of having high-resolution mean sea-surface and slope-correction data for SWOT, made possible thanks to new products based on 20 years of satellite altimetry data.

The meeting achieved all its objectives, and demonstrated a high degree of interaction among SWOT Science and Project Team members, setting the stage for important work to be completed prior to the project CDR. The next SWOT Science Team Meeting will take place during June 2018 in Montreal, Canada. ■

[8] The Discharge Algorithm Working Group's *Pepsi Challenge* is an activity that tests discharge results from different inversion algorithms, all of which use the same assumptions and multiple-river hydraulic model dataset (width, height, slope).
[9] Speckle noise degrades the quality of active radar, synthetic aperture radar (SAR), medical ultrasound, and optical coherence tomography images. In this context, it refers to the impact it has on interferometric SAR images, where coherence of waves reflected from many elementary scatterers degrades the quality of the interferogram.

# NASA Missions Working Together for Improved Atmospheric Data: ICESat-2 Convenes Joint Atmospheric Tutorial

*contined from page 25*

atmospheric measurements that will be valuable for research. Particularly, these include polar clouds, aerosol, and blowing snow. Other measurements—such as cirrus cloud properties, global cloud fraction, smoke from fires, and volcanic eruptions—will also be important contributions from ICESat-2. There are some applications that require near-real-time data, which may prove difficult for the project to provide.

**Conclusion**

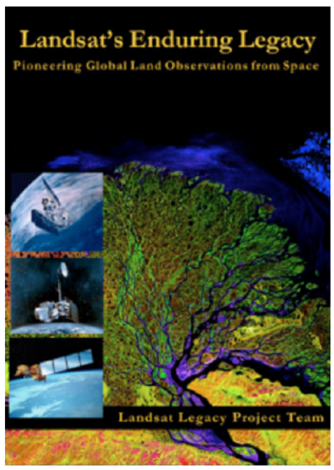
The Joint Atmospheric Tutorial provided an opportunity to obtain ideas from the scientific and operational communities on how to best use ICESat-2 atmospheric data, as well as thoughts on how to tackle some of the unique challenges that the ICESat-2 atmospheric data will present. Participants found it inspiring to learn what each participating group is doing, and were enthusiastic about continued interactions moving forward. Overall, the tutorial allowed participants to familiarize themselves with the different missions and their atmospheric data products and to identify potential synergies for improving atmospheric data. ■



## Publication of Landsat Legacy Book Set for November

After more than 15 years of research and writing, the Landsat Legacy Project Team[*] is about to publish, in collaboration with the American Society for Photogrammetry and Remote Sensing (ASPRS), a seminal work on the nearly half-century of monitoring Earth's lands with Landsat. Born of technologies that evolved from the Second World War, Landsat not only pioneered global land monitoring, in the process it also drove innovation in digital imaging technologies and encouraged development of global imagery archives. Access to this imagery led to early breakthroughs in natural resources assessments, particularly for agriculture, forestry, and geology. The technical Landsat remote sensing revolution detailed in the Landsat Legacy Book was not simple or straightforward. Early conflicts between civilian and defense satellite remote sensing users gave way to disagreements over whether the Landsat system should be a public service or a private enterprise. The failed attempts to privatize Landsat nearly led to its demise. Only the combined engagement of civilian and defense organizations ultimately saved this pioneer satellite-based land-monitoring program. With the emergence of twenty-first century Earth system science research, the full value of the Landsat concept and its continuous 45-year global archive has been recognized and embraced. Discussion of Landsat's future continues, but its heritage will not be forgotten. The pioneering satellite system's vital history is captured in this notable volume on Landsat's Enduring Legacy. The book will be published prior to the Pecora 20 meeting (in Sioux Falls, SD, November 14-16, 2017) and will be unveiled at a special evening session at that conference. Another celebration to mark the publication of the book is being planned; it will take place at the library at NASA's Goddard Space Flight Center (GSFC) some time in December.

[*]***Landsat Legacy Project Team***
**Samuel N. Goward** [University of Maryland, College Park, Department of Geographical Sciences—*Professor Emeritus*]
**Darrel L. Williams** [Global Science & Technology, Inc.]
**Terry Arvidson** [GSFC/Leidos Innovations Corporation]
**Laura E. P. Rocchio** [GSFC/Science Systems and Applications, Inc. (SSAI)]
**James R. Irons** [GSFC]
**Carol A. Russell** [GSFC/SSAI]
**Shaida S. Johnston** [The Aerospace Corporation]




Special $65[**] advance publication price. Hurry, this special price won't last. After November 17, 2017, the price will go up to the published rate.

Order online at *www.asprs.org/landsat.*

[**]Plus postage, shipping for one to three books will be approximately $15.00 for US domestic shipping. The books will be available for shipping in November.

# ESIP in 2017: Strengthening the Ties between Observations and User Communities

*Erin Robinson, Earth Science Information Partners, erinrobinson@esipfed.org*

**Introduction**

The 2017 Earth Science Information Partners (ESIP) Summer Meeting was held at the Indiana Memorial Union on the campus of Indiana University, Bloomington (IU), July 25-28. Nearly 300 members of the Earth science informatics community attended and discussed current trends, problems, and emerging issues affecting the community. The three days of plenary talks, breakout sessions, and technical workshops loosely addressed the annual theme: *Strengthen the ties between observations and user communities*. This focus reflects the ESIP community's desire to address each of the four goals articulated in the strategic plan adopted in January 2015—see *ESIP's Vision Evolves—The 2015–2020 Strategic Plan* (below). In 2017 ESIP is focusing on the second goal. What follows is a summary the summer meeting as well as highlights on the recent activity of the ESIPs—see *ESIP News* on page 34. Each of the Summer Meeting plenary talks can be viewed at *https://www.youtube.com/watch?v=8fP4M0iAYGs*.

## ESIP's Vision Evolves—The 2015–2020 Strategic Plan

NASA founded ESIP (which was formerly known as the Federation of ESIPs) in 1998, in response to a National Research Council (NRC) review of the Earth Observing System Data and Information System (EOSDIS). From its inception, ESIP's mission has been to support the networking and data dissemination needs of our members and the global community generally by linking the functional sectors of observation, research, application, education, and—ultimately—the use of Earth science data and information.

Two earlier strategic plans reflected the evolving nature of ESIP. The 2004 Strategic Plan was intended to raise the visibility of Earth science information and position the ESIP community to improve its data and information delivery infrastructure. That plan conveyed a vision that served as an important rallying point around which ESIP sharpened its focus and continued its growth. Subsequently, the 2009 Strategic Plan celebrated the special status ESIP occupied as a 10-year-old organization, having employed a variety of tools to facilitate communication and interaction using traditional and virtual tools.

Now preparing to enter its third decade, the 2015–2020 plan reflects ESIP's vision to be a leader in promoting the collection, stewardship, and use of Earth science data, information, and knowledge that is responsive to societal needs. This most recent plan recognizes that ESIP is uniquely positioned to respond to the growing need for information to solve Earth's pressing environmental problems and to support the public's interest in making better use of scientific information. ESIP's strength continues to come from its diverse partner organizations, including all Earth-observation data centers from NASA, National Oceanic and Atmospheric Administration, and U.S. Geological Survey; government research laboratories; research universities; nonprofit organizations; and commercial enterprises.

To achieve the ESIP's mission, the 2015-2020 strategic plan identifies four primary goals:

1. Increase the use and value of Earth science data and information.
2. Strengthen the ties between observations and user communities (e.g., technologies, research, education and applications).
3. Promote techniques to articulate and measure the socioeconomic value and benefit of Earth science data, information, and applications.
4. Position ESIP to play a major role in Earth science issues (e.g., addressing effects of climate-change mitigation and adaptation and supporting sustainable science data infrastructure).

After a preamble and descriptive information on the process and "roadmap" used to create it, the vision and mission follow, and then an outline of strategic themes for each goal, with specific objectives and actions. The implementation plan is intended to be a living (i.e., dynamic) document that will be updated frequently, responding to community input throughout its life and reflecting the priorities set by partners who participate in ESIP activities.

The plan is available for download at *http://wiki.esipfed.org/index.php/2015-2020_Strategic_Plan.*

One of the most compelling examples of how ESIP is intentionally seeking to strengthen connections between the observations and user communities is a collaboration between the ESIP Disaster Lifecycle Cluster[1] and the All Hazards Consortium (*http://www.ahcusa.org/who-is-the-ahc.html*), which seeks to establish and/or strengthen connections between ESIP members who have access to relevant Earth observations and utility companies preparing and responding to disasters. The three candidate datasets that are being explored are: the Rapid Event Album CollecTions (REACT), from the University of Alabama in Huntsville, the Tropical Cyclone Information System from NASA/Jet Propulsion Laboratory (JPL), and the Dartmouth Flood Observatory. This defines what it means for data to be "trusted" and builds on the *RL concept[2] with Operational Readiness Levels (ORLs). For more information about the Disaster Lifecycle Cluster work or to get involved see the ESIP Disaster Lifecycle wiki at *http://wiki.esipfed.org/index.php/Disasters*.

During the three-day ESIP Summer Meeting, topics and activities ranged from hands-on demonstrations of cloud computing tools; a hierarchical data format (HDF) workshop; a usability work-a-thon; a science communication training session, to better communicate with policymakers; and a teacher workshop, that brought local teachers to a drone flight school.

Full meeting proceedings are available at *https://2017esipsummermeeting.sched.com*. For a summary of recent and upcoming ESIP activities see *ESIP News Update* on page 34.

**Plenary Activities**

The Summer Meeting had just one plenary session so as to devote as much time as possible to working sessions. The presentations highlighted different examples where and how the observation and user communities are making mutually beneficial connections.

**Patricia Reiff** [Rice University] discussed preparing for the total solar eclipse of Monday, August 21, 2017, which has also been called the "Great American Eclipse." She explained that all of North America will be treated to a solar eclipse, and that anyone within the *path of totality*—where the moon will completely cover the sun—would see a total solar eclipse. The path of totality will stretch along a narrow swath from Lincoln City, OR, to Charleston, SC. Observers outside this path will still see a partial solar eclipse, where the moon covers only part of the sun's disk.[3]

**Caren Remillard** [University of Georgia] was this years Raskin Scholar.);[4] she discussed "Bridging the Gap between NASA Earth Observations and Decision Makers." She discussed two DEVELOP projects from the University of Georgia node that illustrated how DEVELOP builds capacity within user communities by increasing their understanding and use of NASA Earth observations. These rapid feasibility projects highlight the capabilities of satellite and aerial Earth observations to address challenges in agriculture, weather, climate, health and air quality, disasters, energy, ecological forecasting, oceans, and water resources. Remillard shared that immersing decision- and policy-makers in these feasibility projects has increased awareness of the capabilities of Earth observations and contributed to the overall appreciation and increased value of tools and resources available to wider decision making community.

**Brandon Montellato** [DJI][5] shared information on the future of drone technology and inspired the ESIP community to think about how drones might be used in their research, including the Ground Station Pro software for automated mission planning. In addition to Brandon's talk, drones and their utility were quite evident at this meeting with teachers learning to fly drones and use them in the classroom, a one-day pre-ESIP workshop on drone data management, and ESIP even had its first group photo ever taken by drone—a "dronie"—see photo on the next page, where ESIP attendees had gathered for the evening reception.

The next two presentations focused on the real-world activities needed to connect Earth observations with the broader public. **Matt Zumwalt** [Protocol Labs] and **Rebecca Lave** [IU] discussed preparing for a more *decentralized web*, where new technologies make it possible to address content in terms of what it is as opposed to where it is located on the web, They discussed how citizens are recognizing the importance of data stewardship and data archives. Over the last year data refuge and data rescue activities have sprung up

[1] ESIP has three types of collaboration areas. Committees are most formal and approved by ESIP Assembly. Working Groups are short-term, task-oriented groups formed by committees. Clusters are the least formal type of collaboration, and can be started by identifying a topic of interest and sending an email to the ESIP vice president.

[2] *RL is a reference to the number of Readiness Levels, such as Technology Readiness Level and Application Readiness Level used at NASA programs. See, e.g., *https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html* for more information on this topic.

[3] To learn more about NASA's coverage of the "2017 Total Solar Eclipse", please see page 4 of this issue.

[4] The Raskin Scholarship is an annual award made by ESIP to a current graduate student or postdoctoral student in the Earth or computer sciences who has an interest in community evolution of Earth science data systems. The scholarship is named for longtime ESIP member Robert G. Raskin, and seeks to promote collaboration, research support, and exposure for talented students.

[5] DJI is not an acronym. See *http://www.dji.com/company.*

*The 2017 ESIP Dronie*. ESIP Spring Meeting participants look up as a drone takes their picture. Drones were prominently featured during the meeting both during plenary session. Also, a Teacher Workshop took place during the meeting (not included in summary report) during which ESIP's Education Committee taught fourteen teachers how to fly drones and use them in the their classrooms—i.e., they taught the teachers "how to fly!" **Photo credit**: Lindsay Barbieri

across the country.[6] These activities have attracted hundreds of volunteers who have spent considerable time and energy working on duplicating federal data. There is a tension with the increased public attention and federal data managers. ESIP's Data Stewardship committee published a statement in April, that explored what would be helpful from citizens and the broader community (*http://www.esipfed.org/press-releases/stronger-together*). Following Lave's presentation, the Data Stewardship committee held a breakout session with a panel to discuss how ESIP might engage with these rescue efforts moving forward.

The second part of the plenary session focused on data activities at IU, with talks from **Jennifer Schopf** [IU, International Networks], **Angie Raymond** [IU, Kelly School of Business], and **Beth Plale** [IU, Co-Director, HathiTrust Research Center]. Schopf talked about hardware and the physical processes of sharing data; Raymond addressed legal implications of "open" data; and Plale talked discussed digitizing texts and the social science perspective on data science.

Finally, the plenary session concluded with a panel discussion organized by ESIP's Information Quality Cluster, co-chaired by **Hampapuram "Rama" Ramapriyan** [NASA's Goddard Space Flight Center, *retired*] and **David Moroni** [NASA/JPL]. The focus of this session was on scientific quality, and especially on a relatively focused topic—Data Uncertainty—that is extremely challenging but critical in both establishing and elevating the user communities' confidence in Earth science data. The panel featured three scientists that answered questions including: how is uncertainty determined and characterized in the products of their research or application? What are the major side effects and limitations of common statistical techniques used to quantify and characterize uncertainty?

**Carol Ann Clayson** [Woods Hole Oceanographic Institution] discussed the importance of creating accurate data information, including uncertainty estimates and data flags, for all steps of the data production and data usage pipeline. She used real-world examples from the creation of a Climate Data Record, the use of satellite and *in situ* data for weather and climate problems, and the development and planning of large programs such as the NASA Earth Science Decadal Survey. Through these examples Clayson highlighted some of the difficulties in producing the metadata for a dataset, as well as some practical uses of these data from the end-user standpoint.

**Amy Braverman** [JPL] discussed why she believes that probabilities should be used to define data uncertainty in the remote sensing context, and the consequences of not doing so. NASA, NOAA, and other space agencies are producing massive quantities of data that will ultimately be used for science and decision making. These data are typically collected by observing systems that capture indirect measurements of the phenomena of interest (e.g., radiances), and then complex algorithms are applied to infer the underlying geophysical phenomena.

**Isla Simpson** [National Center for Atmospheric Research] discussed the challenges in evaluating global climate models with limited observational data records. For many aspects of both climatology and shorter-term climate variability, the limited observational data record results in an uncertain ground truth against which to compare our models. The case of the Northern Hemisphere extra-tropical circulation response to the El Niño Southern Oscillation (ENSO) was presented as an example. Substantial uncertainties exist on the composite mean response to ENSO over the limited observational record due, in large part, to internal atmospheric variability (i.e., weather noise).

[6] Read about one example of data rescue in "Dark Data Rescue: Shedding New Light on Old Photons" in the May–June 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 3**, pp. 4-10—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May-Jun%202014_final_color508.pdf*].

## ESIP News Update

*ESIP adds seven new members.* Seven new members have joined ESIP this summer—see **Table**—bringing total membership of ESIP to 180 organizations. Members are divided into three categories: data providers (Type I), researchers (Type II), and application developers (Type III).

ESIP community members are exposed to new technology and emerging concepts in Earth data science, and work to advance Earth science information best practices in an open, transparent fashion. Membership in ESIP is voluntary, and open to organizations that work at the intersection of Earth science data and supporting technologies.

**Table.** New member organizations welcomed at the ESIP Summer Meeting.

| Member Organizations | Member Category |
|---|---|
| Air Sciences, Inc. | Type III |
| Department of Geographical Sciences (GEOG), University of Maryland | Type II |
| U.S. Environmental Protection Agency's Information Access and Analytical Services Division | Type II |
| Neptune and Company, Inc. | Type III |
| New Knowledge Organization Ltd. | Type III |
| Climate Generation: A Will Steger Legacy | Type III |
| University of Notre Dame/Center for Research Computing (UND-CRC) | Type III |

*ESIP Turns 20 in 2018!* ESIP will celebrate its twentieth anniversary in 2018. As part of that celebration we are looking for stories from the community about how ESIP has impacted members' work. If you have a story, please share it on the #myesipstory ESIP-ALL Slack channel or email *staff@esipfed.org*. Thanks in advance!

*ESIP Community at AGU.* ESIP will be represented at the American Geophysical Union's (AGU) Fall Meeting in New Orleans, LA, December 11-15, 2017. Three particular activities that could be of interest to the ESIP community are the AGU Data Fair, the Data Help Desk, and *Ignite@AGU*. The Data Fair, a partnership between AGU and ESIP, includes a data-related keynote address on Monday evening, December 15, and three lunchtime panels that will help bridge gaps between data practitioners and domain-area scientists. ESIP will also co-host a data help desk near the AGU Publications booth with other data organizations including DataOne, DataCite, Data Conservancy, and AGU Earth and Space Science Informatics (ESSI)—*http://essi.agu.org*. The second activity is the annual *Ignite@AGU*, where speakers must adhere to a strict presentation format of five minutes' length and 20 slides that auto-advance every 15 seconds. The rapid-fire pace of this format makes for a fun-filled, frenetic delivery and keeps the audience engaged. Ignite presenters span domains and organizations, and range from graduate students to senior-level researchers, science journalists, educators, and others. Some talks are about serious science while others are more lighthearted, but all focus on a compelling idea or story. Ignite talks are not your average scientific conference talks—speakers are encouraged to push boundaries and be creative, funny, and thought-provoking. The call for sessions will be shared in early October.

*2018 ESIP Winter Meeting.* The 2018 ESIP Winter Meeting will be held January 9-11 in Bethesda, MD. ESIP meetings are open to everyone, and typically draw around 300 attendees from diverse Earth-, space-, and environmental-science backgrounds. The call for session proposals will be open until October 15; sessions may be related to the 2018 theme: *Promote techniques to articulate and measure the socioeconomic value and benefit of Earth science data, information, and applications.* The meeting will also focus on other topics relevant to the ESIP community. Visit *www.esipfed.org* to learn more about the Winter Meeting.

*Weekly email updates.* The ESIP Monday Update is a weekly email that summarizes recent ESIP news and upcoming activities of interest, such as workshops, telecons, funding, and job opportunities. To subscribe to this mailing list or view recent Monday Updates, visit *http://www.esipfed.org/news.*

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# Summary of the MERRA-2 Applications Workshop

*Margaret Hurwitz, NASA's Goddard Space Flight Center/Science Systems and Applications, Inc., margaret.m.hurwitz@nasa.gov*

## Introduction

A meteorological reanalysis incorporates historical weather-related data into a "fixed version" of a numerical model of the atmosphere, i.e., the model version does not change throughout the entire reanalysis time period. In the specific case of the Modern-Era Retrospective analysis for Research and Applications, Version 2, or MERRA-2 reanalysis, the system is based heavily on NASA observations and the Goddard Earth Observing System, Version 5 (GEOS-5) numerical model. Bringing together MERRA-2 developers, data scientists, researchers, communications specialists, and program managers, the MERRA-2 Applications Workshop took place June 19, 2017, at NASA's Goddard Space Flight Center (GSFC). The workshop brought together approximately 80 professionals, both in person and remotely, representing GSFC, other U.S. government agencies, academia, nongovernmental organizations, and the commercial sector. The objectives of the event were to:

- Increase the visibility of MERRA-2 for a wide variety of applications;
- identify cases where MERRA-2 is being used to support decision making;
- identify the stakeholder community's needs in terms of MERRA-2 output, analytic services, and training; and
- enhance the network of MERRA-2 developers, researchers, and end-users—particularly in the Washington, DC area.

The following summary presents the highlights of the day-long workshop. Some of the presentations given will soon be available at *https://science.gsfc.nasa.gov/610/applied-sciences/climate_applications_wg.html*.

## Opening Remarks

Both **Steve Platnick** [GSFC—*Deputy Director for Atmospheres, Earth Science Division*] and **Woody Turner** [NASA Headquarters (HQ)—*Program Manager for Ecological Forecasting, Applied Sciences*] gave words of welcome to the meeting participants, one on behalf of GSFC, and the other from NASA HQ. During their remarks, each speaker noted that the event was the first large-scale attempt to coordinate the activities of end-users of the MERRA-2 reanalysis product and to better understand their needs and challenges. **Maggie Hurwitz** [GSFC—*Deputy Applied Sciences Manager*] explained that the workshop fits into GSFC's portfolio of applied sciences activities through its Climate Applications Working Group—GSFC-based scientists and applied sciences leaders seeking to share their experience and to enhance the uptake of GSFC's climate-related and model-based products by end-users.

## Overview of MERRA-2 and Related NASA Computing Resources

The morning's first session provided overviews of the MERRA-2 reanalysis product and related NASA computing resources, as well as the process of obtaining and manipulating MERRA-2 output. **Steven Pawson** and **Mike Bosilovich** [both at GSFC] explained that MERRA-2 is created by combining numerous atmospheric datasets with a fixed version of GEOS-5 (1980–present) to produce complete records of hundreds of Earth-system fields (e.g., winds), all of which are consistent both in space and time. Bosilovich noted the advances of MERRA-2 as compared with MERRA-1—e.g., MERRA-2 is better at capturing extreme precipitation and providing aerosol fields—and emphasized that his team is working towards developing a reanalysis of the entire Earth system. He noted that MERRA-2 fields can be downloaded from the Goddard Earth Sciences Data and Information Center (GES DISC) website (*https://disc.gsfc.nasa.gov*). **Dana Ostrenga** [GSFC] highlighted the GES DISC's subsetting and regridding tool, which allows application users to select specific fields, time periods, and regions of interest. **John Schnase** [GSFC] noted that at ~400 Tb for the entire MERRA-2 collection, it is a burden to download and store, and that it is difficult and time-consuming to perform simple operations on MERRA fields (e.g., computing mean values). In response, MERRA Analytic Services, a tool still in beta testing, was developed to combine high-performance computing [via the NASA Center for Climate Simulation (NCCS)] and web services to reduce the data burden. **Ana Prados** [GSFC] noted that NASA's Applied Remote Sensing Training (ARSET) program helps end-users learn how to download and manipulate MERRA-2 fields, with particular utility in monitoring climate variability, analyzing extreme weather events, and providing hydrometeorological inputs to decision-support tools.

## MERRA-2 Earth Science Applications

The morning's second session showcased seven applications of MERRA-2 for weather, climate, water, and agriculture. **Ken Kunkel** [North Carolina Institute for Climate Studies] and **Jim Biard** [North Carolina State University] explained how they combine MERRA-2 fields and pattern-recognition software to identify weather fronts. **Allie Collow** [GSFC] described her research using MERRA-2 to identify the contributions of frontal and low-pressure weather systems to extreme precipitation events in the northeast U.S. **Robert Field** [NASA Goddard Institute for Space Studies (GISS)] described the Global Fire Weather Database (GFWED), which is based on the Fire Weather Index (FWI) System (*http://cwfis.cfs.nrcan.gc.ca/background/summary/fwi*) and integrates the weather factors influencing the likelihood of a vegetation fire starting and spreading—*https://data.giss.nasa.gov/impacts/gfwed*. His analysis focused on the link between weather conditions (summarized by the FWI) and the burned area—see **Figure**. **Mark Carroll** [GSFC] showed how the Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) wildfire decision support tool (*http://giscenter.isu.edu/Research/Techpg/nasa_RECOVER/index.htm*) can produce burned-area maps within five minutes. The NASA-funded State of the Global Water and Energy Cycle Project (SGWECP) uses MERRA-2 to constrain the global water budget; **Tim Donato** [George Mason University (GMU)], representing GMU's SGWECP, noted that the representation of the global water budget varies across satellite datasets and reanalyses, and that more research is needed in this area.

**Kristi Arsenault** [GSFC] noted that MERRA-2 fields underpin NASA's Land Information System (LIS)—*https://lis.gsfc.nasa.gov*—which ultimately provides forecasts of growing conditions to the Famine Early Warning System Network (FEWS NET)—*https://www.fews.net*. **Alex Ruane** [GISS] discussed the Agricultural Model Intercomparison and Improvement Project (AgMIP)—*http://www.agmip.org*—in which agricultural model simulations are intercompared using a standardized climate-forcing dataset (AgMERRA) that is based on MERRA fields. AgMERRA provides gap-filled time series of weather-related fields (e.g., temperature), particularly useful in developing countries where there may be no local measurements.

**Andrea Molod** [GSFC] and **Maggie Hurwitz** moderated a panel discussion with several of the NASA speakers—see photo below. Speakers discussed the potential decrease in the latency of MERRA fields and the concomitant increase in the utility of MERRA-2 for near-real-time applications and analysis. MERRA-2 users praised the continuity of the MERRA-2 products over 38 years of output, which provide historical context and estimates of interannual variability—information sorely needed for agricultural applications.

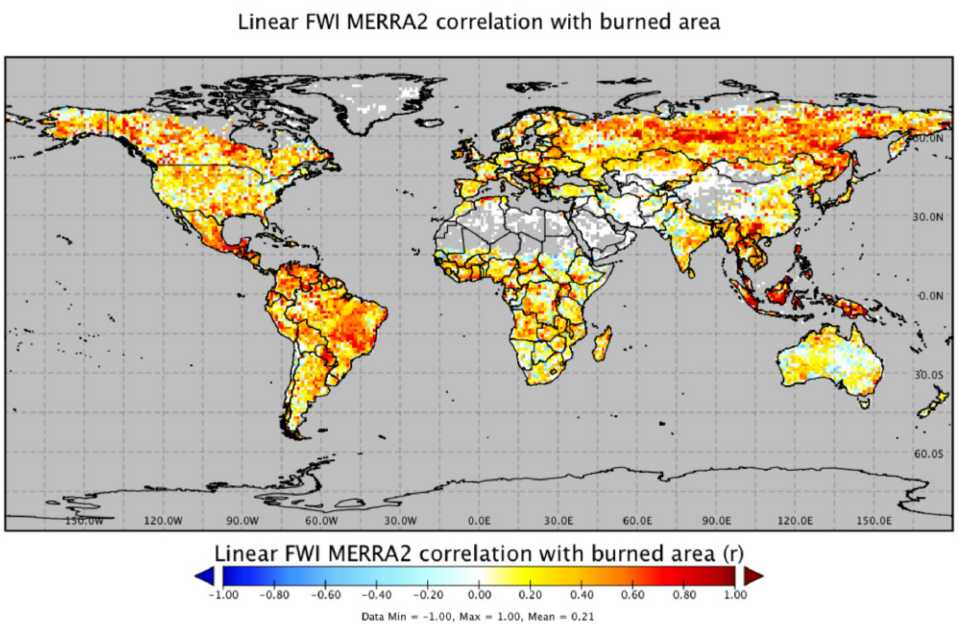
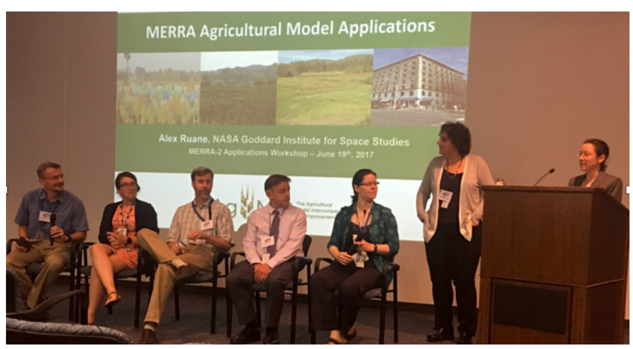



**Figure**. The map shows the correlation between burned area and Fire Weather Index (FWI)—which is computed using MERRA-2 data (1981-present)—at the peak of the local fire season. Calculations of FWI based on the National Oceanic and Atmospheric Administration's (NOAA's) Climate Prediction Center (CPC) precipitation measurement yield similar results. **Image credit**: Robert Field




**Andrea Molod** [*standing*] and **Maggie Hurwitz** [*behind lectern*] chaired a panel discussion, during which the panelists articulated why MERRA-2 is a great resource for end users, and how they expect the MERRA series of products to evolve in the coming years. Panelists included [*left to right*]: Mike Bosilovich, Dana Ostrenga, Mark Carroll, Steven Pawson, and Kristi Arsenault [all GSFC]. **Photo credit:** Robin Kovach

**MERRA-2 Applications Beyond Earth Science**

The early afternoon session showcased six applications of the MERRA-2 reanalysis beyond the Earth science community, in the areas of renewable energy, civil engineering, and public health. **Mark Stoelinga** [Vaisala] noted the importance of MERRA-2's 50-m (~164-ft) altitude wind fields to the wind energy sector; Stoelinga said that analyses using both the current and previous version of MERRA have increased the understanding of near-surface wind fields and thus informed significant investment decisions in the renewable energy sector. Likewise, **Manajit Sengupta** [National Renewable Energy Laboratory] noted the importance of MERRA-2 in driving the National Solar Radiation Database (*http://rredc.nrel.gov/solar/old_data/nsrdb*), a tool used in solar energy prospecting and solar generator design. Both Sengupta and Stoelinga noted that end-users in their respective fields have adopted MERRA-2 because of its relatively low data latency and observation-quality datasets, as compared with other reanalyses—e.g., the ECMWF family of reanalysis products (*https://www.ecmwf.int/en/research/climate-reanalysis*). **Paul Stackhouse** [NASA's Langley Research Center] stated that MERRA-2 has been used to define the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' (ASHRAE) building climate zones. MERRA-2 fields have underpinned research carried out by **Chuck Schwartz** [University of Maryland, College Park] on the sensitivity of pavement materials to weather parameters. **Jen Stowell** [Emory University] showcased her research group's studies using remote sensing to study the health effects of air pollution; she explained that the MERRA-2 reanalysis could augment this research by providing additional fields (e.g., aerosols) at high spatial resolution over a long study period. **Antar Jutla** [West Virginia University] outlined the use of MERRA-2 and other reanalyses in understanding water-borne infectious disease. In particular, hydrometeorological fields from MERRA-2, again in combination with pattern recognition software, are being used to understand the seasonality and evolution of cholera outbreaks, to plan vaccination programs, and ultimately to mitigate cholera risks.

**Parallel Sessions**

The midafternoon activities featured three parallel discussion sections, summarized below.

***Using MERRA-2 for Case Study and Recent Event Analysis***

The first section, led by **Allie Collow** [GSFC] and **Robert Field** [GISS], discussed the use of MERRA-2 for case studies and recent event analyses. MERRA-2 users noted that it would be helpful to know which observations fed into the reanalysis at a particular time, as well as the associated uncertainties, explaining that for extreme event studies at small scales, it would be helpful if the MERRA-2 output were released with both UTC and local time labels.

***Using MERRA-2 for Planning and Design for Climate Variations***

**Mike Bosilovoch** and **Allison Leidner** [NASA HQ] chaired a discussion about planning and designing for climate variations. Participants explained that data consistency is highly valued by reanalysis end-users, so MERRA producers should attempt to minimize discontinuities related to data processing or changes in the observing system. The group's consensus was that end-users would like to make use of MERRA-2 time series to compute trends and analyze climate extremes. Likewise, the group agreed that end-users highly value the length of the data record that MERRA-2 provides (1980-present), which is being used to characterize drought, climate variability, decadal oscillations, and *climate analogues*—places that experience similar conditions, but may be separated in space or time. Participants recommended that future versions of MERRA continue to offer long time series, and include data over land (i.e., by incorporating soil moisture and surface temperature observations into the reanalysis), as well as dynamic vegetation models.

***MERRA Analytics and Related Software Tools for Accessing MERRA Fields***

**John Schnase** and **Enidia Santiago-Arce** [GSFC] led a session during which participants discussed MERRA Analytic Services and related software tools to access MERRA fields. Schnase noted that MERRA Analytic Services is working toward processing and comparing with other reanalyses (e.g., the ECMWF family of reanalysis products), and will be able to handle ensembles of reanalyses in the future. Santiago-Arce discussed mechanisms for the government to engage with and distribute software (e.g., decision-support tools) to the private sector.

**Discussion Session Wrap-Up**

**Danielle Wood** [GSFC—*Former Applied Sciences Manager*] led the closing large-group discussion, which tied together the key points raised during the parallel sessions and throughout the workshop. Participants noted that extensive documentation, the large collection of data fields, and the availability of related tools (e.g., Giovanni)[1] enhance the value of MERRA-2 for a wide range of applications.

[1] Giovanni stands for Goddard Earth Sciences Data and Information Services Center (GES-DISC) Interactive Online Visualization ANd aNalysis Infrastructure. To learn more, read "The Second Gregory G. Leptoukh Online Giovanni Workshop" in the May–June 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 3**, pp. 14-18—*https://go.nasa.gov/2h40UKg*]. Giovanni can be accessed at *https://giovanni.gsfc.nasa.gov/giovanni*.

### Closing Remarks

The workshop was successful by all accounts. Participants responded to brief surveys both before and after the workshop, with responses that show that all participants felt that the workshop enhanced their knowledge about the MERRA-2 reanalysis and its wide range of applications. Before the workshop, 30% of respondents said they had a high level of expertise with MERRA; this number increased to 50% after the workshop. Many participants reported that they made new contacts, thereby enhancing the end-user community and increasing end-users' awareness of NASA resources.

Survey responses also indicated interest in a second MERRA-2 applications workshop. Such a workshop could address how to access new data analytics tools and interfaces to further facilitate access to and use of data, techniques for downscaling MERRA-2 output for fine-scale applications, guidance for trend analysis, and working with temporal artifacts in the MERRA-2 collection. A second workshop might focus on a particular thematic area, such as natural disaster analysis or renewable energy applications. Participants were keen to collaborate with NASA's Global Modeling and Assimilation Office (GMAO) to better incorporate the needs of applications users into the next generation of MERRA products. Meanwhile, existing and planned ARSET Program training courses will help participants access and process the MERRA-2 fields needed for their particular research and related applications. ■

## ESIP in 2017: Strengthening the Ties between Observations and User Communities

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### Conclusion

The 2017 ESIP Summer Meeting brought together a diverse, cross-sector and -domain community to address common problems. The most important takeaway from ESIP meeting attendees is always the value and importance of networking across the Earth science data and informatics community. ESIP allows individuals to put their work in a broader context and find new connections that enrich their professional lives. The meeting is just the beginning of such fruitful collaborations. We are grateful for the continued support from the ESIP community and their rich contributions to this meeting. ■

# Summary of the Spring 2017 NASA Land-Cover and Land-Use Change Science Team Meeting

*Sumalika Biswas, University of Maryland, College Park, sbiswas2@umd.edu*
*Chris Justice, University of Maryland, College Park, cjustice@umd.edu*
*Garik Gutman, NASA Headquarters, ggutman@nasa.gov*

## Introduction

The Spring 2017 NASA Land-Cover and Land-Use Change (LCLUC) Science Team Meeting was held on April 12-13, 2017, at the Hilton Washington, DC/Rockville Hotel & Executive Meeting Center in Rockville, MD. The meeting focused on LCLUC on mountainous regions, and a variety of synthesis studies and Multi-source Land Imaging (MuSLI) projects. The two-day event was organized into eight sessions, with four sessions each day. More than 100 participants, including scientists, post-doctoral scientists, graduate students, and researchers from academia and government agencies attended the meeting. The meeting presentations can be accessed at *http://lcluc.umd.edu/meetings/2017-lcluc-spring-science-team-meeting-apr-12th-13th-and-musli-meeting-april-14th*.

## Day 1: Opening Remarks, Invited Talks, Discussion of LCLUC in Mountainous Regions, Poster Session

**Garik Gutman** [NASA Headquarters (HQ)—*LCLUC Program Manager*] opened the meeting by sharing the importance of the date in space science history: April 12 was the International Day of Human Space Flight, the night of which is popularly known as *Yuri's Night*. He explained that it was on this day in 1961 that Yuri Gagarin took the first human space flight, marking the beginning of future space exploration for the benefit of humankind. He followed by paying tribute to **Piers Sellers**, a former colleague, astronaut, scientist, deputy director of the Sciences and Exploration Directorate at NASA Headquarters, and director of the Earth Sciences Division at NASA's Goddard Space Flight Center, who passed away in December 2016 of pancreatic cancer.[1] Gutman then gave updates on recent LCLUC activities, project updates, and developments.

**Chris Justice** [University of Maryland, College Park (UMD)—*Program Scientist*] followed with program updates and discussed the meeting agenda. He noted that some projects in recent NASA LCLUC solicitations [e.g., Research Opportunities in Space and Earth Sciences (ROSES) calls] are being led by social scientists, implying the increasing maturity of social science aspects of LCLUC. He also invited suggestions for potential areas for future directions of the LCLUC

Participants at the NASA LCLUC Spring 2017 Science Team Meeting. **Photo credit**: Kristofer Lasko

program. Justice offered three recommendations for future research, which were to: focus on South America as the next regional initiative [i.e., after the South Asia Research Initiative (SARI)[2] is complete]; explore the link between globalization and land-use change (e.g., markets and soybean expansions); and focus on LCLUC in Africa, exploring the integration of *smallholders*—tenants of small farms that rely on mainly family labor—into market economies and food security and the linkage to the Sustainable Development Goals (SDG). Justice emphasized strengthening the relationships with partner programs with respect to common issues such as forecasting in the land sector, managing land-use interactions and tradeoffs, and land conflicts.

Two invited talks took place on the first day. **Jack Kaye** [NASA HQ—*Associate Director of Research for the Earth Science Division*] presented the broader current and future NASA interests and activities. He explained that with a fleet of Earth-observing missions currently in orbit, it is an exciting time for Earth-observation science and applications. He added that the variety of sensors enables multiple datasets at multiple scales across all geographic regions. To facilitate processing the large

[1] Read the "In Memoriam" for Piers Sellers in the January–February 2017 issue of *The Earth Observer* [**Volume 29, Issue 1**, pp. 4-5—*https://go.nasa.gov/2gaUrR5*]. Also see *https://go.nasa.gov/2gbBIVo* to read his memoriam by Chris Scolese, NASA's Goddard Space Flight Center's Center Director.

[2] Read about a recent SARI Agricultural Workshop on page 44 of this issue. A number of the presenters at the LCLUC meeting also gave similar presentations at the SARI workshop.

volume of input data, he advocated the use of NASA Earth Exchange (NEX).[3] In addition to NASA's satellites, similar moderate-resolution sensors operated by other countries—like Japan, India, South Korea, and various countries in Europe—provide improved opportunities for land cover mapping applications and land-use science.

**Allison Thomson** [Field to Market—*Science and Research Director*] provided an introduction and update on the Global Land Programme (GLP)—*https://glp.earth*—which was established in 2005 as a cosponsored project of the Internationl Human Dimentions Programme on Global Environmental Change (IHDP)/ International Geosphere-Biosphere Programme (IGBP). She explained that the central task of GLP is the identification of scientific priorities and agenda settings through synthesis of existing knowledge, meta-analysis of land-based research, and targeted workshops. Thomson concluded that GLP provides a platform for the land system science community through networking activities. The GLP is interested in Earth Observations and welcomes increased cooperation with NASA's LCLUC program.

After the invited talks came several presentations focusing on LCLUC studies in mountainous regions gleaned from projects selected from LCLUC ROSES 2013. The projects addressed a range of factors that impact LCLUC in those mountainous regions, including environmental, social, economic, and political drivers.

**Volker Radeloff** [University of Wisconsin, Madison] spoke about the impact of wars on land use in the Caucasus region, which is situated at the border of Eastern Europe and Western Asia, between the Black Sea and the Caspian Sea. He showed the case studies of two mountainous areas, Nagorno–Karabakh (internationally recognized as part of Azerbaijan) and Chechnya. In each case, wars resulted in extensive agricultural abandonment near conflict areas, destroying settlements, and the growth of new agriculture in nearby Azerbaijan for Nagorno-Karabakh. Radeloff noted that, while war in these regions has had a significant impact of urban and agricultural areas in both these regions, the impact on existing forest cover, in his opinion, was less than might have been expected. He stated that his research found that wars had a stronger effect on land-use change in the Caucasus than did the collapse of the Union of Soviet Socialist Republics (USSR).

[3] NEX is a virtual collaborative computing environment that brings scientists together in a knowledge-based social network that provides the necessary tools, computing power, and access to big data to accelerate research, and innovation and to provide transparency. The goal of NEX is to improve efficiency and expand the scope of NASA's Earth science technology, research, and applications programs. Learn more at *https://nex.nasa.gov/nex*.

**Dan Slayback** [NASA's Goddard Space Flight Center (GSFC)] discussed the impact of climatic and socioeconomic drivers on high-altitude, tropical Andean alpine wetlands, called *bofedals*—peat bogs with rich dark soils that act like enormous sponges, capturing water from rain and snowmelt. He explained that the bofedals in the region consist of a dense carpet of cushion plants[4] and provide critical year-round nutritious forage for populations of llama and alpaca, which play an important economic role in the highland system of pastoral agriculture. He described how his group's project integrates climate models, hydrology, and biology to better understand the relevant physical processes, and as aids to local adaptation.

**Jefferson Fox** [East-West Center—*Director of the Research Program*] showed how he and others at the East–West Center[5] in Hawaii are mapping forest dynamics in the middle hills of Nepal. The mapping approach they use includes a rigorous evaluation of terrain correction methods and a Landsat-based disturbance detection algorithm in a cloud-computing framework. He showed the spatial distribution of hotspots of forest cover growth and loss across Nepal, and discussed his results with respect to the spread of Nepal's *community forests*[6] and remittance income arising from foreign labor migration.

**Giorgos Mountrakis** [State University of New York, Syracuse] discussed the impact of sociopolitical and environmental factors on grazing in the Altai Mountains in Russia, Kazakhstan, China, and Mongolia. His initial results show that after the fall of the USSR in 1991, China's grazing system remained the same (i.e., carefully planned, heavily subsidized, and intensive), while those in Russia and Kazakhstan dwindled, and those in Mongolia expanded with changes in herd composition.

**Andrew Hansen** [Montana State University—*Director of the Landscape Biodiversity Lab*] presented his results on LCLUC under different Intergovernmental Panel on Climate Change (IPCC) scenarios across northwestern U.S. mountain landscapes using the Spatially Explicit Regional Growth Model (SERGoM Model). He described how his group applied the results to address vulnerability assessments of biodiversity in response to

[4] A cushion plant is a low-growing plant, characterized by a tightly knit structure, that has a mat- or cushion-like appearance. They are commonly found in the Alpine Tundra and high-altitude areas. They help other plants to adapt to harsh conditions.

[5] Established by the U.S. Congress in 1960, the East-West Center serves as a resource for information and analysis on critical issues of common concern, and bringing people together to exchange views, build expertise, and develop policy options.

[6] Community forestry is a successful participatory approach for forest protection and management in Nepal. It is estimated that 850,000 ha of forests in Nepal have been handed over to 11,000 forest user groups.

future global change. His presentation examined rates of change of spatial patterns and change in exurban development, and tested hypotheses on the relative and context-dependent influence of proximity to cities and markets, natural resources, natural amenities, and climate change.

**Geoff Henebry** [South Dakota State University—*Codirector of the Geospatial Sciences Center of Excellence*] gave a presentation titled *How Environmental Change in Central Asian Highlands Impacts High Elevation Communities*. His team's research focuses on documenting environmental change at four different human settlements (and associated pasturelands) in the Kyrgyz Republic: At-Bashy and Naryn in Naryn oblast,[7] and Alay and Chong-Alay in Osh oblast. At each location the following four attributes are monitored: *changes in the thermal regime*—e.g., growing season timing and extremes; *changes in the moisture regime*—e.g., peak precipitation timing and onset and duration of snow cover; *changes in socio-economic conditions*—e.g., impacts of globalization through labor migration and remittance income; and *changes in land cover, land use, and land condition*—e.g., alterations in terrain. His results discussed the influences of snow-cover melt date and snow-cover duration on land-surface phenology as modulated by terrain.

A poster session closed out the first day of the meeting. It was preceded by a *rapid poster introduction*, where participants had the opportunity to give two-minute summaries to introduce themselves and their research to the meeting participants. The purpose of this session was to help to connect individuals working on closely related topics. To see a list of the posters presented, visit *http://lcluc.umd.edu/documents/lcluc-2017-poster-presentations*.

### Day 2: Opening Keynote, Synthesis Studies, MuSLI Projects

**Volker Radeloff** began the second day of the meeting with a keynote address on *Structural transformation, increasing returns to scale and land use change—or a proposal for a unified land use theory*. He proposed a conceptual model and outlined the contribution of three economic theories: land rent theory, new growth theory, and new trade theory[8] to his proposed model. The land rent theory proposes that the most valuable crop is grown in the most fertile soil implying comparative advantage in specialization and trade. He also noted that transportation costs impact land rent, and that this results in land use ring formation around cities where the outermost circle is comprised of wasteland while the innermost circle comprises of residential areas. The new growth theory proposes that accumulated knowledge leads to new technology which in turn leads to economic growth. The new trade theory proposed the existence of agglomeration patterns resulting in core and periphery formations connected by trade. However, each of these theories on its own has deficiencies and is unable to explain current global land use patterns on its own. Radeloff proposed a conceptual model and used his proposed model to explain real-world land-use trends like urban teleconnections, forest transition trends in the U.S. and urban sprawl in maturing economies.

*Synthesis Studies*

After the keynote presentation there was a series of presentations that covered a variety of synthesis projects funded under LCLUC ROSES 2013 selections, as outlined below.

**Karen Seto** [Yale University] presented a synthesis of LCLUC studies on urbanization, exploring the contribution of urban remote sensing studies to urban LCLUC science, sustainability, and the functioning of Earth's systems. She explained that, while globally land agricultural land lost due to urban expansion is relatively small, regional losses will be acute in the future, which is expected to lead to significant loss of staple crops in Asia and Africa.

**Dan Brown** [University of Michigan—*Director of the Environmental Spatial Analysis Laboratory*] discussed large-scale land transactions as drivers of land-cover change in Sub-Saharan Africa. Brown stated that according to the *land matrix*—an online public database on land deals (*http://www.landmatrix.org/en*)—the global extent of land transactions extends to 40.6 M ha, about 100 times the size of the state of Rhode Island. He added that most of these transactions are clustered in South-East Asia, Africa, South America, and Eastern Europe. Brown concluded that the projects he and others are carrying out are designed to study land transactions in three countries in Africa in a quasi-experimental framework. The projects also seek to identify and examine the link between LCLUC and land tenure.

**Peilei Fan** [Michigan State University] presented information on urbanization and sustainability under conditions of global change and in transitional economies—a synthesis from Southeast, East, and North Asia (SENA). Fan identified diverging patterns of urban LCLUC at different spatial and temporal scales, and successfully applied Bayesian sequential learning for global urban land mapping, hybrid mapping, informal settlement mapping, and multidisciplinary methods for mapping historical land-use changes. The major drivers and spatial determinants were economic developments (e.g., globalization, industrialization), institutions (role of government policies), urban land use, and environmental quality.

[7] An oblast is an administrative region that is considered autonomous.

[8] These theories address various how supply and demand of several parameters vary as a function of several aspects of human behavior.

*Multi-Source Land Imaging (MuSLI) Projects*

The Multi-source Land Imaging (MuSLI) projects session consisted of seven project updates. The objective of this session was to report on the current status of progress in these areas and to discuss issues that the community may have with respect to data processing and use of Landsat and Sentinel[9] images.

**Nathan Torbick** [Applied GeoSolutions] reported that for rice mapping applications, blending moderate-resolution radar data with optical data obtained from the Sentinel-1, Phased Array type L-band Synthetic Aperture Radar (PALSAR-2),[10] and Landsat-8 platforms generated the best overall classified Land Use/Land Cover maps. Torbick stated that Sentinel-1 data are particularly useful for use in assessing and monitoring rice at moderate scales over large cloud-prone regions using a phenology-based approach. He added that PALSAR-2 data show promise in research activities but are not ideal for operational monitoring due to insufficient image availability

**Chengquan Huang** [UMD] showed the feasibility of using MuSLI Harmonized Landsat and Sentinel (HLS) products to monitor terrestrial surface inundation (e.g., wetlands, ponds). He explained how his group developed automated surface-water mapping algorithms and that they are now testing the algorithms over various test sites (e.g., Saskatchewan Prairie Pothole, Delmarva Peninsula, Florida Everglades). He stated that validation remains a challenge due to the high spatial and temporal resolution of the developed products and the absence of suitable validation datasets.

**David Roy** [South Dakota State University] reported on developing a prototype of a Landsat-8/Sentinel-2 global burned-area product for Southern Africa. The work builds on his experience with the Landsat WELD project and MODIS burned area mapping and validation. He pointed out issues in preprocessing Sentinel-2 data and the need for a continued dialogue between NASA representatives and their European Space Agency (ESA) counterparts on instrument performance and data processing.

[9] The first five Sentinel missions were discussed in "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15—*https://go.nasa.gov/2xt90Gu*]. For more information about Sentinel—including Sentinel 1-6—see *http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4*.

[10] PALSAR-2 flies on the Japan Aerospace Exploration Agency's (JAXA) Advanced Land Observing Satellite-2 (ALOS-2).

**Joe Sexton** [UMD] discussed a project that involves multisource imaging of a time-series of tree and surface-water coverage at continental-to-global scales. He and his colleagues determined that fusion of multisensor optical estimates of tree-canopy and surface-water cover was possible, but that C-band measurements alone are not useful for estimating tree cover. However, by combining C-band data with data at optical or other synthetic aperture radar wavelengths, the tree-cover estimates improve significantly. His group also found L-band polarimetry data useful for estimating tree cover and discriminating natural from plantation forests.

**Chris Small** [Columbia University] reported on the multisource imaging of infrastructure and urban growth using data from Landsat, Sentinel, and the Shuttle Radar Topography Mission (SRTM). He explained how he developed a continuous index to map the continuum of human settlements worldwide using optical and microwave datasets, and discussed the challenges of using his results to perform urban mapping.

**Marc Friedl** [Boston University] presented information on multisource imaging of seasonal dynamics in land-surface phenology; in particular, he shared his experiences using a fusion approach that employs data from Landsat and Sentinel-2. He and his colleagues used the MUultivariate Imputation by Chained Equations (MICE) method to fill in data gaps. Time series analysis of *image stacks*[11] showed sensitivity to subtle landscape patterns. This means that small changes in land cover characteristics over time influence the algorithm output.

**Matt Hansen** [UMD] spoke on integrating data from Landsat 7 and 8 as well as Sentinel 2 to improve crop-type identification and area estimation in the U.S. and Argentina. He demonstrated his approach applying large volume data processing to crop-area estimation methods and discussed the challenges associated with such an approach, such as the impact on estimates based land fragmentation and small field size.

There was also a session on International Programs and Capacity Building that focused on South/Southeast Asia. Three relevant programs support or are closely linked to some LCLUC projects in this region: SARI, SERVIR,[12] and the Monsoon Asia Integrated Research on Sustainability–Future Earth (MAIRS-FE). Because the focus of these discussions was more programmatic than data related, these are discussed in *LCLUC Programs and Capacity Building in South/Southeast Asia* on page 43.

[11] An image stack is a series of two-dimensional images "stacked" to produce a set of volume (i.e., three-dimensional) data.

[12] SERVIR is not an acronym. It means "to serve" in Spanish and French.

## LCLUC Programs and Capacity Building in South/Southeast Asia

**Krishna Vadrevu** [NASA's Marshall Space Flight Center] presented information on the South Asia Research Initiative (SARI—*http://www.sari.umd.edu*), which was formed in response to international LCLUC meetings in the region, highlighting the need for land-cover science products to meet regional science priorities. Projects focusing on regional science priorities were selected during the ROSES 2015 NASA solicitation that cover forests, agriculture and food security, urban development, and human health. SARI has a strong emphasis on applied research with regional and national societal applications and benefits and strengthening regional and national projects through experimental codesign and collaboration in implementation and data analysis.*

**Nancy Searby** [NASA HQ] discussed SERVIR, which is a joint NASA/USAID program focused on the use of earth observations for societal benefit. The NASA-SERVIR Program (*https://www.nasa.gov/mission_pages/servir/index.html*)—through the SERVIR-Mekong hub—supports SARI and helps in capacity building and training to meet regional needs by strengthening the relationships between research institutions and product end-users, with support from local governments.

**Jiaquo Qi** [Michigan State University] gave a presentation on the the Monsoon Asia Integrated Research on Sustainability and its connection to Future Earth (MAIRS-FE). MAIRS-FE (*http://www.futureearth.org/projects/mairs-fe*) is another regional consortium that operates in South and Southeast Asia. It was formerly supported by NASA's LCLUC program but now operates under Future Earth.** The MAIRS region is characterized by monsoon climate, topography, and rapid economic growth. The projects that MAIRS supports focus on issues of regional priority such as sustainable food, water and energy systems, vulnerability to natural disasters, and rapid urbanization.

*Learn more about a recent SARI Agricultural Workshop on page 44 of this issue.
**Future Earth is a major international research platform providing the knowledge and support to accelerate transformations to a sustainable world (*http://www.futureearth.org*).

### Closing Activities

**Chris Justice** closed with summaries of the several discussions. Various issues raised during different sessions during the meeting were discussed, including retaining synthesis as an element of future LCLUC calls, further integration of LCLUC and social science, and the need for proposers to LCLUC to familiarize themselves with the program website and the research that has been funded to-date. Suggestions on synthesis projects leading to workshops, books, and directions for the future research agenda were welcomed. Participants expressed the need for further integration of LCLUC with social science, especially economics, by including economists in the projects without sacrificing the remote-sensing science involved. Opportunities between NASA and ESA for joint calls and solicitations were suggested for MuSLI projects so that scientists funded by both agencies can work to prevent duplication of efforts. The potential role of commercial data providers in enabling LCLUC science was also discussed.

**Garik Gutman** closed the meeting with a meeting summary and notifications. He proposed to retain the social science component as an integral part of the LCLUC proposals except for special thematic calls, such as MUSLI, which are remote-sensing oriented. He encouraged continuing efforts with multisource land-imaging applications and proposed to continue support for SARI and the Northern Eurasia Future Initiative (NEFI)[13] through future solicitations and meetings. Participants were encouraged to contribute to the program though webinars, on Facebook, and by sharing their publications, news, and datasets at the LCLUC website. ■

[13] The NEFI, formerly called the Northern Eurasian Earth Science Partnership Initiative (NEESPI), was earlier supported by LCLUC but now has moved to Future Earth. LCLUC is helping with the transition phase.

# Summary of the 2017 South/Southeast Asia Research Initiative Agricultural Workshop

*Krishna Prasad Vadrevu, NASA's Marshall Space Flight Center, krishna.p.vadrevu@nasa.gov*
*Chris Justice, University of Maryland, College Park, cjustice@umd.edu*

**Introduction**

South/Southeast Asian countries are growing rapidly in terms of population, industrialization, and urbanization. As a result of this growth, one of the key policy challenges facing the region is *food security*—conditions "…when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life."[1] Although total food production has increased in the region since 1960 due to land area having been converted to agricultural use, more recently it has decreased, mostly due to loss of productive agricultural land due to urbanization and industrial development. Furthermore, the region is experiencing variability in the timing of the monsoon and extreme weather events, resulting in drought or flooding, which impact agricultural production. Monitoring crop production in a timely manner is essential to predict and prepare for disruptions in the food supply. To achieve such timely monitoring requires improved and up-to-date information on agricultural land-use practices.

Although there has been significant progress in remote sensing and geospatial technologies over the past few decades, there has been little emphasis placed on developing robust methods for operational mapping and monitoring of areas devoted to crops. In South/Southeast Asia generally, most mapping efforts to date have focused on the broader classification of land cover types and generalized cropland areas into a single or limited number of thematic classes. Only a few countries have access to up-to-date crop type information. There is an urgent need to make this near-real-time information more readily available to stakeholders and to enhance national and regional operational systems for monitoring agricultural crops.

To address these issues and the potential and limitations of different remote sensing data and methods for agricultural applications, an international workshop, titled *Operational Mapping/Monitoring of Agricultural Crops in South/Southeast Asian Countries—Research Needs and Priorities*, took place May 2-4, 2017, at the Guru Gobind Singh (GGS) Indraprastha University in New Delhi, India—see **Photo 1** below. The workshop was organized as a part of the South/Southeast Asia Research Initiative (SARI)[2] activities.

The workshop was organized into four sessions:

- Global/regional programs in agriculture;
- computational tools and decision-support systems for agricultural research;
- biophysical parameter retrievals, crop type, area and yield mapping and monitoring; and
- regional land and agriculture mapping and monitoring activities.

[1] Definition from the Food and Agriculture Organization of the United Nations. See *www.fao.org/forestry/13128-0e6f36f27e0091055bec28ebe830f46b3.pdf* for details.

[2] SARI was initiated by NASA's Land Cover and Land Use Change (LCLUC) Program to promote innovative regional research, education, and capacity-building activities involving state-of-the-art remote sensing, natural sciences, engineering, and social sciences to enrich LCLUC science in South/Southeast Asia (*www.sari.umd.edu*). Learn more about recent activities of NASA's LCLUC Science Team on page 39 of this issue.

**Photo 1.** SARI Agricultural Workshop Participants—New Delhi, India. **Photo credit:** GGS Indraprastha University Team

In addition, two discussion sessions were organized, titled *User Community Needs on Food Security and Agriculture in South/Southeast Asia* and *Satellite Based Agricultural Research Needs and Next Steps in South/Southeast Asia*. Key findings from the workshop sessions and discussions are summarized in the remainder of this article. The workshop presentations can be downloaded at *http://sari.umd.edu/meetings/operational-mappingmonitoring-agricultural-crops-southsoutheast-asian-countries-%E2%80%93research*.

**Opening Remarks**

The meeting began with welcoming remarks from **Anubha Kaushik** [GGS Indraprastha University—*Dean of the University School of Environmental Management*]. She stated that 58% of the rural households in India depend on agriculture as their principal means of livelihood, and that monitoring crops on an operational basis will help in crop-damage and yield assessments, irrigation scheduling, and tailoring of agronomic practices.

**Krishna Vadrevu** [NASA's Marshall Space Flight Center (MSFC)—*SARI Lead*] then provided an update on SARI activities and meeting objectives. He explained that SARI is serving as a facilitator and catalyst for LCLUC research in South/Southeast Asia, with an emphasis on applied research with regional and national societal focus and benefits. SARI is strengthening regional and national projects through codesign and collaborations involving regional and international researchers from different universities, institutes, and operational agencies. Vadrevu stated that SARI meetings and training help identify research needs and priorities in the region and provide impetus to land-use science in the region. He highlighted the workshop objectives, which included reviewing existing methodologies and sources of data relating to operational mapping and crop monitoring in the SARI region; gathering information and sharing experiences; identifying regional needs and priorities; and providing a forum for collaboration among the various initiatives and institutions related to agricultural remote sensing. Vadrevu stated that agriculture is the backbone for the economy in SARI countries, and there is a strong need to generate reliable cropland area statistics, within-season crop type and condition, production, and yield estimates on an operational basis.

**Global/Regional Programs in Agriculture**

**Chris Justice** [University of Maryland, College Park (UMD), U.S.] presented information on the Group on Earth Observations' (GEO), Global Agricultural Monitoring [GEOGLAM] initiative, which was first endorsed by the Group of Twenty (G20) Agriculture Ministers in June 2011 in Paris, France. GEOGLAM promotes and supports reliable, accurate, timely, and sustained national crop-monitoring information and yield forecasts. He described the development of the UMD agricultural monitoring activities, which started in 2005 with efforts by NASA and the U.S. Department of Agriculture to transition crop analysis from the Advanced Very High Resolution Radiometer (AVHRR)[3] to the Moderate Resolution Imaging Spectroradiometer (MODIS).[4] One of the best examples of GEOGLAM regional coordination is the Asia-Rice project (*http://www.asia-rice.org*). The target products include rice crop area estimates and maps, crop calendars, crop damage assessment, agrometeorological information products, production estimates, and forecasting.

**Christina Justice** [UMD] described the GEOGLAM Crop Monitor for Early Warning project. The objective of the Crop Monitor (*https://cropmonitor.org*) is to strengthen agricultural decision making through exchanging information, building consensus, and reducing uncertainty in countries most vulnerable to food insecurity. Crop condition information is compiled regularly from international and in-country agricultural experts, and is reviewed and published on the first Thursday of every month. The monthly bulletins started in February 2016, thus providing an international consensus on the condition of the 10 main food security crops for each region addressed by the project.

**Prakash Chauhan** [Space Applications Center (SAC), India] highlighted activities in remote sensing of agriculture carried out at SAC. He reported that recently the Indian Space Research Organization (ISRO) has had a busy launch schedule. During 2016 alone, ISRO launched Resourcesat-2A, SCATSAT-1, Cartosat 2C/2D/2E, and INSAT-3DR; Cartosat-3, Oceansat-3, and GISAT are planned for launch in 2017-18.[5] He stated that India has been using space technology for agriculture applications for almost 45 years and that data from instruments on these missions—the Linear Imaging Self-scanning Sensor-3 (LISS III), Advanced Wide-Field Sensor (AWiFS), synthetic aperture radar (SAR), and scatterometer—are routinely used for crop mapping and monitoring. Satellite-based, value-added, agrometeorological products are available for India through the Visualization of Earth Observation Data and Archival System (Vedas) portal (*https://vedas.sac.gov.in/vedas*). In addition, other web portals are being

[3] AVHRR flew/flies on a series of National Oceanic and Atmospheric Administration (NOAA) Polar-orbiting Observational Satellite (POES) missions [NOAA 6–NOAA 19]; copies also fly on the European Space Agency's MetOp-A and -B missions;

[4] MODIS flies on NASA's Terra and Aqua satellites.

[5] All the satellites mentioned in this sentence of Indian Earth Observation satellites are the satellite names, i.e., none of them are acronyms. Learn more about each individual mission at *http://www.isro.gov.in/spacecraft/list-of-earth-observation-satellites*.

used to disseminate remote sensing data and products to end-users.[6]

**Shibendu Ray** [Mahalanobis National Crop Forecast Center (MNCFC), India] described the operational mapping and monitoring of agricultural crops in India. MNCFC was inaugurated on April 23, 2012, with a mandate to use geospatial technology for agricultural assessment. MNCFC contributes to different national agricultural programs providing information on crop mapping and yield forecasting, agrometeorology, drought assessment, horticulture inventory, crop insurance, and rice-fallow-area characterization. MNCFC is collaborating with 20 different state agricultural departments, 12 state horticultural departments, and 16 different state remote sensing centers in addition to different ISRO centers and the Indian Council for Agricultural Research centers on agricultural activities.

**Computational Tools and Decision Support Systems for Agricultural Research**

**Uttam Kumar** [NASA's Ames Research Center, U.S.] presented results from a case study that used subpixel learning algorithms to estimate global land-cover fractions using high-performance computing analysis via the NASA Earth Exchange (NEX).[7] Validation of land fractions over California revealed a 6% improvement from using an "unmixing"-based classifier compared to a per-pixel-based Random Forest classifier.

**Thenkabail Prasad** [USGS, U.S.] presented details on the Global Food and Water Security-support Analysis Data (GFSAD) project. He reported that the beta version of world's first 30-m (~98-ft) global cropland extent product for 2015 has been produced using a combination of Landsat 30-m and Sentinel-2[8] 10-m (~32-ft) and 20-m (~65-ft) time-series data using the Google Earth Engine platform. As per the dataset, croplands occupy 12% of the Earth's land area. **Gumma Muralikrishna** [International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India], another GFSAD team member, presented details on cropland versus noncropland masks, irrigated versus rain-fed croplands, cropping intensity, and cropland pattern maps for South Asia for the period 2000 through 2014, using MODIS 250-m (~820-ft) resolution satellite data and semi-automated techniques. More details about the project, relevant datasets, and publications can be found at *https://geography.wr.usgs.gov/science/croplands*.

**Nathan Torbick** [Applied Geosolutions Inc., U.S.] described large-area rice mapping for Myanmar, which integrated Landsat-8, Sentinel-1, and Phased Array type L-band Synthetic Aperture Radar (PALSAR-2)[9] datasets, using a random forest algorithm. He showed that for 2015 the total cropland area for Myanmar was 186,701 $km^2$ and the harvested rice area was 66,521.11 $km^2$. Torbick stated that production was down since 2009, and the yield is lowest in the region. He mentioned that many agricultural areas of Myanmar remain extremely vulnerable to stressors.

The session also included presentations from the Remote sensing-based Information and Insurance for Crops in Emerging economies (RIICE) team, which is a public–private partnership organized to reduce the vulnerability of smallholder rice farmers in low-income countries in Asia and beyond—*http://www.riice.org/about-riice*. RIICE uses remote sensing to map rice growth in selected regions in Asia and helps governments make the necessary provisions to meet potential food shortages and to better manage the risks, including agricultural insurance solutions to protect rice smallholders. **Manoj Yadav** [RIICE Team] gave a specific example of RIICE application in Tamil Nadu, India. An automated processing chain involving multi-temporal SAR images was developed to predict in-season and end-of-season yield estimates in addition to rice area, seasonality, and phenology maps. **Nasreen Khan** [International Rice Research Institute (IRRI), Philippines) described RIICE services specific to yield estimation. She showed that the MAPscape (*http://www.mapscape.eu*) RIICE tool developed by Sarmap (*http://www.sarmap.ch*) is mainly used to derive spatial and temporal information on crop growth, including establishment date and leaf area index (LAI) while the crop simulation model "ORYZA" (*https://sites.google.com/a/irri.org/oryza2000/about-oryza-version-3*) is used for yield forecasting and estimation.

**Karan Choudhary** [Ministry of Agriculture and Farmers Welfare, India) presented material on operational agricultural drought assessments in India, where the National Agricultural Drought Assessment and

[6] Examples include the Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC), National Natural Resource Management System (NNRMS), India-Water Resources Information System (WRIS), Bhuvan (the ISRO Geoportal), and the National Remote Sensing Centre (NRSC) Decision Support Center.

[7] NEX is a virtual collaborative computing environment that brings scientists together in a knowledge-based social network that provides the necessary tools, computing power, and access to big data to accelerate research, and innovation and to provide transparency. The goal of NEX is to improve efficiency and expand the scope of NASA's Earth science technology, research, and applications programs. Learn more at *https://nex.nasa.gov/nex*.

[8] The first five Sentinel missions were discussed in "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/July_Aug_2013_508_color.pdf*]. For more information—including Sentinel-6—please see *http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4*.

[9] PALSAR-2 flies on the Japan Aerospace Exploration Agency's (JAXA) Advanced Land Observing Satellite-2 (ALOS-2).

Monitoring System (NADAMS) has been developed to integrate remote sensing indices, rainfall soil moisture, ground truth on sowing progression, and irrigation statistics. Monthly and fortnightly district-level drought assessments for 14 agriculturally dominant Indian states (including 6 at the subdistrict level) are provided. Drought warnings (with normal, watch, and alert designations) are given in June, July, and August, while drought assessments (with mild, moderate, and severe designations) are provided during September and October. Many states in India proactively use the NADAMS-based early-warning assessments to characterize drought conditions and prospects.

**Biophysical Parameter Retrievals, Crop Type, Area and Yield Mapping/Monitoring**

**Vinay Sehgal** [Indian Agricultural Research Institute (IARI), India] presented several case studies on the retrieval of plant biophysical parameter and phenology trends for croplands using satellite remote sensing. Landsat 8 data were tested for utility in estimating leaf area index (LAI) using the Pro-SAIL radiative-transfer model (RTM)[10] suggested that there is fairly strong correlation ($r^2$=0.78) between the *in situ* and retrieved LAI values. Sehgal also discussed results from comparing two atmospheric correction algorithms (LIbRadtran versus MODTRAN) applied to Sentinel-2 data. The analysis suggests that MODTRAN-corrected data showed a better correlation between estimated LAI and retrieved LAI. The LAI inputs from the RTM are also being used for wheat crop yield modelling studies by IARI.

Wetlands are very important for food security for rural populations in India. Wetland agriculture includes cultivating paddy rice, fox nut, water chestnut, and lotus. **Jai Garg** [GGS Indraprastha University, India] described the automated mapping and monitoring of wetlands for the cultivation of wetland crops in India. Data from AWiFS on the Indian Remote Sensing (IRS) satellite at 56-m (~184-ft) resolution was used for wetland mapping for India, where total wetlands account for about 15 M ha. Currently, efforts are underway to update the national wetlands inventory for India.

**S. Mamatha** [MNCFC] highlighted that an area assessment for the seven major horticultural crops (i.e., banana, mango, citrus, potato, onion, tomato, and chili peppers) in selected districts of India is being generated using IRS-AWiFS and Sentinel-2 data, using pixel- and object-based classification approaches.

[10] PROSAIL is a combination of the PROSPECT leaf optical properties model and SAIL canopy bidirectional reflectance model, which is suited to study plant canopy spectral and directional reflectance in the solar domain.

Three different presentations focused on wheat mapping: two in India and one in Pakistan. **Ruth DeFries** [Columbia University, U.S.] and her colleagues used MODIS enhanced vegetation index data to develop maps of winter wheat production in India from 2000 to the present at 1-km (~3280-ft) resolution. She also showed that winter cropping and mechanization related to agricultural fires is affecting the air quality in New Delhi. **Meha Jain** [University of Michigan, U.S.] highlighted the use of Landsat and SkySat (*https://www.satimagingcorp.com/satellite-sensors/skysat-1*) data to map mean wheat yield from 2000 to 2015 in the Indo-Ganges region. Crop model simulations were used to predict yields based on the simulated vegetation index values from the satellites on a given day. The method is effective as one can predict crop yield for any single day in the growing season using remote sensing inputs. Presenting on behalf of **Matt Hansen** [UMD], **Christina Justice** showed results from a case study on winter wheat mapping over Pakistan, which integrated Landsat data and very-high [5-m (~16-ft)]-resolution imagery from the RapidEye satellite (*https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/rapideye*). The results suggest that high-resolution imagery can be used to create training points for effective classification when field sizes are small. **Varun Tiwari** and **Mir Matin** [ICIMOD, Nepal] presented a method for mapping wheat in Afghanistan using Sentinel-2 data in a Google Earth Engine framework.

**Krishna Vadrevu** returned to discuss the use of Sentinel-1A SAR data to map rice in the Red River Delta, Vietnam. He showed that targeted acquisitions at selected phenological stages can provide results as accurate as a full time-series, with more than 90% accuracy—and with 40% fewer images. The results from this study identified growth stages important for rice mapping in Vietnam. **Neetu** [MNCFC, India] showcased the potential of Radarsat-2 and RISAT-1 SAR data for crop mapping and monitoring studies in India. For example, they were able to use this data to successfully estimate district and state-wide rice acreage for the months of July–October in 2012 and 2013. Similar efforts are underway to map other crops—e.g., cotton and maize—using SAR data to provide village-level crop-area estimates. In addition, MNCFC has also been able to successfully estimate biomass of different crops in the state of Bihar during 2015 and 2016. Finally, SAR data has been shown to have the potential to estimate the area of rice paddies that were flooded in the state of Odisha in the aftermath of Cyclone Phailin.

**Noorullah Stanikzai** [Ministry of Agriculture, Irrigation and Livestock, Afghanistan] presented information on rice crop area estimation and rice crop mask development for 2016 in Afghanistan integrating

PROBA-V,[11] SPOT-6/7,[12] Pleiades,[13] Sentinel-1 and -2, and Landsat 8 data. PROBA-V data were used to delineate cropping patterns, whereas the SPOT-6/7 and Pleiades data were used to delineate agricultural land. Sentinel-1, Sentinel-2, and Landsat 8 data were used for rice classification and area estimation.

**A.K. Baxla** [India Meteorological Department] showed that preharvest and in-season crop yield forecasts at national, state, and district levels in India are being implemented as a part of the Forecasting Agriculture using Space, Agrometeorology and Land (FASAL)-based observations project. Both statistical and simulation models are used for yield forecasting. Baxla further showed that simulation model refinement is underway by experimental testing across diverse environment, soil, and cultural practices, using data from forty-seven field units spread over different agro-climatic zones in India. **Nilabja Ghosh** [Institute of Economic Growth, India] showed that econometric modeling is used to determine early-season forecasting of crop yields as a part of the FASAL, with input explanatory variables such as crop and fertilizer costs, weather, irrigation, technology, and policy.

**Anand Khobragade** [Maharashtra Remote Sensing Applications Centre] presented the potential and limitations of soft classification approaches and found that Support Vector machine-based classification appears to be most suitable for agriculture applications. Also, specific to contextual algorithms, spatial AdaBoost and Markov Random Field (MRF) classifiers showed excellent performance at much lower computational cost.

**Sandeep Patakumari** [Anna University, India] explained that tank irrigation is one of the oldest and continuing practices in India, and highlighted the importance of tank rehabilitation projects for a case study in Kancheepuram District, Tamil Nadu, India, as they can provide equitable, reliable, and adequate water distribution to the local populations.

[11] PROBA-V is the fourth satellite in ESA's PROBA series; the "V" stands for vegetation.
[12] SPOT stands for Satellite Pour l'Observation de la Terre, a French commercial, high-resolution, Earth-imaging system run by Spot Image in Toulouse, France.
[13] The European Pleiades constellation (Pleiades-HR 1A and Pleiades-HR 1B) provides coverage of Earth's surface every 26 days.

### Regional Land and Agricultural Mapping/ Monitoring Activities

In this session, several projects were showcased. **Kyathsandra Manjunath** [ISRO] discussed mapping rice phenology in South/Southeast Asia using SPOT-4 vegetation data. Rice maps were derived by integrating 30-m Shuttle Radar Topography Mission (SRTM) digital elevation maps with irrigation, flood, and rainfall maps and normalized difference vegetation index (NDVI) data in a clustering method. Manjunath also highlighted future Indian Earth-observing missions useful for agricultural applications.

**S.K. Choudhari** and **Obi Reddy** [both from the Indian Council of Agricultural Research, India] presented remote sensing applications for natural resource mapping in India. They showed that Landsat Thematic Mapper data can be used for physiographic mapping of India at a 1:250,000 scale and that IRS-P6 LISS-IV and Sentinel-2 data in conjunction with Cartosat-1 digital elevation model data are used for landform and land degradation mapping at a 1:10,000 scale.

**Brijendra Pateria** [Punjab Remote Sensing Center (PRSC), India] presented information on remote sensing activities by PRSC, including a web-based application—titled Agro-Geoinformatics—for water, soil, and crop data collection, useful to address farmers' agricultural needs. Currently, district-level crop acreage and yield estimation is being generated for paddy, maize, cotton, wheat, winter vegetables, and other summer-season crops using multi-satellite imagery.

**Ramesh Hooda** [Haryana Space Applications Center (HARSAC), India] summarized remote sensing applications in agriculture in Haryana state in India. As a part of the FASAL project, HARSAC produces estimates of wheat, mustard, paddy, cotton, and sugarcane in Haryana. HARSAC is also involved in developing land-use plans, rice-stubble burnt-area mapping,

**Photo 2**. Leftover crop residues after wheat-crop harvesting using a combine—Moradabad, Uttar Pradesh, India. **Photo credit**: Krishna Vadrevu

soil-fertility mapping, crop-damage assessment, and ground-water-mapping studies. Crop residue mapping (an example of which residue is shown in **Photo 2**) is highly important in this region, as most farmers burn crop residues, thereby causing intense air pollution. **Ashwin Tumma** [IIC Technologies, India] presented results from another case study, which highlighted the use of IRS P6-Resourcesat LISS III data at a resolution of 23.5 m (77 ft) to delineate mango plantations in Krishnagiri District, Tamil Nadu, and how geospatial technologies can aid farmers to identify suitable market outlets.

**Nabin Yadav**, **Faisal Qamer**, and **Mir Matin** [ICIMOD, Nepal] presented details of an operational agricultural monitoring system operating in Nepal. The system was developed as a part of the NASA SERVIR[14] project (*https://www.nasa.gov/mission_pages/servir/index.html*). An agriculture area mask was developed using Landsat 8 data from 2014 through 2016 for Nepal. Both Sentinel-1 and Sentinel-2 data are being used to generate crop calendars. A pilot study for Chitwan District is using Sentinel-2 data for maize, wheat, rice, and mustard mapping. An automated crop-type mapping and in-season crop sown-area assessment for Nepal is underway, using machine-learning algorithms and cloud computing platforms.

**Mustafa Kamal** [International Maize and Wheat Improvement Center (CIMMYT), Bangladesh] presented remote sensing activities carried out by CIMMYT. He showcased two different projects, one relating to surface water irrigation suitability mapping using Landsat 7 and 8 data and another on estimating crop water use for irrigation scheduling using a Tetracam camera mounted on an unmanned aerial vehicle. The camera has both visible and thermal bands, useful in detecting canopy temperature and thus, water stress.

## Conclusion

The workshop presentations focused on synergies among various approaches and provided recommendations on how to improve the role of Earth observations, ground-based (*in situ*) data, and modeling techniques to map and monitor different crops in space and over time. The workshop brought together experts from both developed and developing countries to identify data gaps and needs related to operational mapping and monitoring of cropped areas in the SARI region. In addition to the presentations, the discussion sessions highlighted the needs and priorities of agricultural research in the region. Panel members identified a variety of user groups—from individual farmers to government ministries—that need to be targeted, and also identified several potential user groups. The panel agreed that the most important "use case" is to reduce risk in agriculture. Other potential use cases included providing forecasts to aid farmer decision making and to facilitate advanced planning (e.g., providing customized weather information or helping with irrigation scheduling); identifying management zones and targeting these with appropriate solutions (e.g., crop suitability maps, infrastructure development plans); and informing crop insurance programs. The group also recommended that those undertaking operational research and development should work closely with local intermediaries (e.g., agricultural advisors and consultants) who can produce useful recommendations from satellite-derived data products.

The attendees unanimously agreed that free and open data policies from all space agencies are needed in the region, to enable the broad use and dissemination of the data. In addition, attention should be given to transitioning basic research to develop operational satellite-based products. Panel members suggested that although new sensors, algorithms, and cloud computing platforms are increasing and transforming the use of remote sensing, there is a strong need to develop best practices for data use, and to provide accuracy assessment protocols for agricultural data products. For robust algorithm testing and validation, ground-truth data are needed. This could be facilitated through access to field data from long-term agricultural sites, for example, in the framework of the GEOGLAM Joint Experiment for Crop Assessment and Monitoring (JECAM) program (*www.jecam.org*). Although India is relatively advanced in operational monitoring of agricultural systems, for other countries in South/Southeast Asia, crop-condition monitoring, yield estimation, agricultural drought assessment, crop type, fallow land and soil mapping, and crop advisories should be developed on a priority basis. Participants suggested that a top priority is to develop customized early-warning systems targeted at farmers and extension agents. In addition, they felt the focus should be on user-driven generation of satellite-derived products. Workshop participants stressed the need for increased capacity building and training activities in the region, and urged the SARI team to organize more thematic workshops and training events in the region. ■

**Request for papers:** As a part of the workshop outputs, papers are being solicited on remote sensing of agriculture in South/Southeast Asia, to be part of a *Special Issue* of the *International Journal Remote Sensing*. All researchers working on remote sensing of agriculture in South/Southeast Asia are invited to submit articles at *http://explore.tandfonline.com/cfp/est/tres-remote-sensing-in-asia-cfp*. Email Krishna Vadrevu (*krishna.p.vadrevu@nasa.gov*) for details.

[14] SERVIR is not an acronym. In Spanish, it means "to serve."

# RAVAN CubeSat Measures Earth's Outgoing Energy

*Samson Reiny, NASA's Goddard Space Flight Center, samson.k.reiny@nasa.gov*

**EDITOR'S NOTE:** This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

An experimental small satellite has successfully collected and delivered data on a key measurement for predicting changes in Earth's climate.

The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat was launched into low-Earth orbit on November 11, 2016, to test new technologies that help to measure Earth's *radiation imbalance*—which is the difference between the amount of energy from the sun that reaches Earth and the amount that is reflected and emitted back into space. That difference, estimated to be less than 1%, is responsible for global warming and climate change.

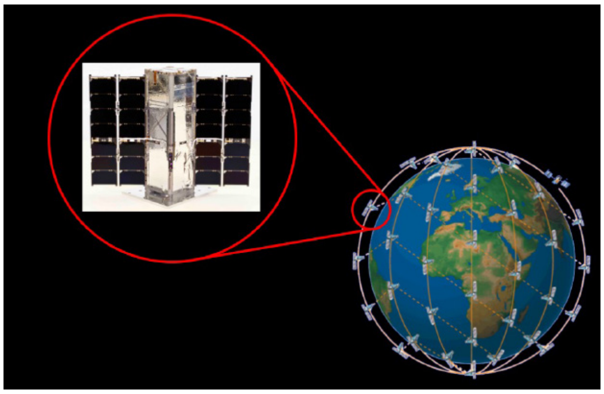


**Figure**. Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) is a three-unit (3U) CubeSat that successfully demonstrated new technologies for measuring the amount of reflected solar and thermal energy that is emitted into space. These observations have the potential to improve spaceborne measurements of Earth's energy imbalance. **Image credit:** Johns Hopkins University's Applied Physics Laboratory (APL)

Designed to measure the amount of reflected solar and thermal energy that is emitted into space, RAVAN employs two technologies that have never before been used on an orbiting spacecraft: *carbon nanotubes* that absorb outbound radiation and a *gallium phase change blackbody* for calibration.

Among the blackest known materials, carbon nanotubes absorb virtually all energy across the electromagnetic spectrum. Their absorptive property makes them well suited for accurately measuring the amount of energy reflected and emitted from Earth. Gallium is a metal that melts—or changes *phase*—at around body temperature, making it a consistent reference point. RAVAN's radiometers measure the amount of energy absorbed by the carbon nanotubes, and the gallium phase change cells monitor the stability of the radiometers.

RAVAN began collecting and sending radiation data on January 25, 2017, and has now been in operation for well past its original six-month mission timeframe.

"We've been making Earth radiation measurements with the carbon nanotubes and doing calibrations with the gallium phase change cells, so we've successfully met our mission objectives," said **Bill Swartz** [Johns Hopkins Applied Physics Laboratory—*RAVAN Principal Investigator*]. He and his team are now monitoring RAVAN in the longer term to see how much the instrument changes over time and are also performing data analysis and comparing its measurements with existing model simulations of outgoing Earth radiation.

While the technology demonstration comprises a single CubeSat in practice, a future RAVAN mission would operate many CubeSats in a constellation—see **Figure**. Instruments for measuring Earth's outgoing energy are currently housed aboard a few large satellites, and while they have a high spatial resolution they cannot observe the entire planet simultaneously the way a constellation of RAVAN CubeSats could, Swartz explained.

"We know that outgoing radiation from Earth varies widely over time depending on variables such as clouds or aerosols or temperature changes," Swartz said. "A constellation can provide a global, 24/7 coverage that would improve these measurements."

"This successful technology demonstration realizes the potential of a new observation scenario to get at a very difficult measurement using constellation missions," said **Charles Norton** [NASA/Jet Propulsion Laboratory, Earth Science Technology Office (ESTO)[1]—*Program Area Associate*]. "In terms of its impact for CubeSats and Smallsats for NASA, I think it has helped to bring forward another example of how this platform can be successfully used for technology maturation, validation, and science."

Small satellites, including CubeSats such as RAVAN, are playing an increasingly larger role in exploration, technology demonstration, scientific research, and educational investigations at NASA, including: planetary space exploration; Earth observations; fundamental Earth and space science; and developing precursor science instruments like cutting-edge laser communications, satellite-to-satellite communications, and autonomous movement capabilities. ■

[1] ESTO supports technologists at NASA centers, industry, and academia to develop and refine new methods for observing Earth from space, from information systems to new components and instruments. ESTO provides funding for RAVAN and other Earth science CubeSat missions in the Earth Science Division.

# NASA/UCI Find Evidence of Sea Level "Fingerprints"

*Alan Buis, NASA/Jet Propulsion Laboratory, alan.d.buis@jpl.nasa.gov*
*Brian Bell, University of California, Irvine, bpbell@uci.edu*

**EDITOR'S NOTE:** This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Researchers from NASA/Jet Propulsion Laboratory (JPL), and the University of California, Irvine (UCI), have reported the first detection of *sea level fingerprints* in ocean observations—i.e., detectable patterns of sea level variability around the world resulting from changes in water storage on Earth's continents and in the mass of ice sheets. The results will give scientists confidence they can use these data to determine how much the sea level will rise at any point on the global ocean as a result of glacier ice melt.

As ice sheets and glaciers undergo climate-related melting, they alter Earth's gravity field, resulting in sea level changes that aren't uniform around the globe. For example, when a glacier loses ice mass, its gravitational attraction is reduced. Ocean waters nearby move away, causing sea level to rise faster far away from the glacier. The resulting pattern of sea level change is known as a sea level fingerprint. Certain regions, particularly in Earth's middle and low latitudes, are hit harder, and Greenland and Antarctica contribute differently to the process. For instance, sea level rise in California and Florida generated by the melting of the Antarctic ice sheet is up to 52% greater than its average effect on the rest of the world.

To calculate sea level fingerprints associated with the loss of ice from glaciers and ice sheets and from changes in land water storage, the team used gravity data collected by the twin satellites of the U.S./German Gravity Recovery and Climate Experiment (GRACE) mission between April 2002 and October 2014—see **Figure**.[1] During that time, the loss of mass from land ice and from changes in land water storage increased global average sea level by about 0.07 in (1.8 mm) per year, with 43% of the increased water mass coming from Greenland, 16% from Antarctica, and 30% from mountain glaciers. The scientists then verified their calculations of sea level fingerprints using readings of ocean-bottom pressure from stations in the tropics.

"Scientists have a solid understanding of the physics of sea level fingerprints, but we've never had a direct detection of the phenomenon until now," said co-author **Isabella Velicogna** [JPL/UCI—*Research Scientist/ Professor of Earth System Science*].

"It was very exciting to observe the sea level fingerprints in the tropics, far from the glaciers and ice sheets," said lead author **Chia-Wei Hsu** [UCI—*Graduate Student*]

The findings are published in the journal *Geophysical Research Letters*. The research project was supported by UCI and NASA's Earth Science Division. ■

[1] An animation showing monthly *sea level fingerprints* from January 2014 to April 2014 can be viewed at *https://www.jpl.nasa.gov/images/grace/20170907/grace20170907-16.gif*.

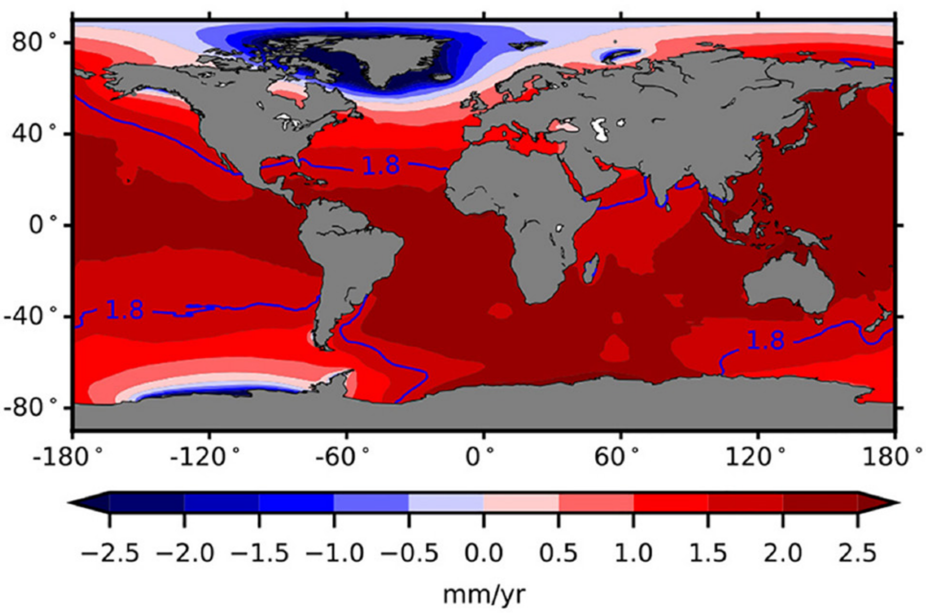



**Figure.** Sea level fingerprints in mm per year calculated from observations of the mass loss of Greenland, Antarctica, glaciers and ice caps, and changes in land water storage using time-variable gravity data collected by the twin satellites of the U.S./German Gravity Recovery and Climate Experiment (GRACE) mission between April 2002 and October 2014. The contour line (1.8 mm/year) is the average sea level rise if the total addition of mass of water to the ocean was spread uniformly over the world's ocean. The sea level fingerprints are not uniform and bulge around the equatorial regions. **Image credit:** Isabella Velicogna and Chia-Wei Hsu/UCI

# A Menacing Line of Hurricanes

*Adam Voiland, NASA's Earth Observatory, adam.p.voiland@nasa.gov*

**EDITOR'S NOTE:** This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Meteorologists struggled to find the right words to describe the situation as a line of three hurricanes—two of them major and all of them threatening land—brewed in the Atlantic basin in September 2017.

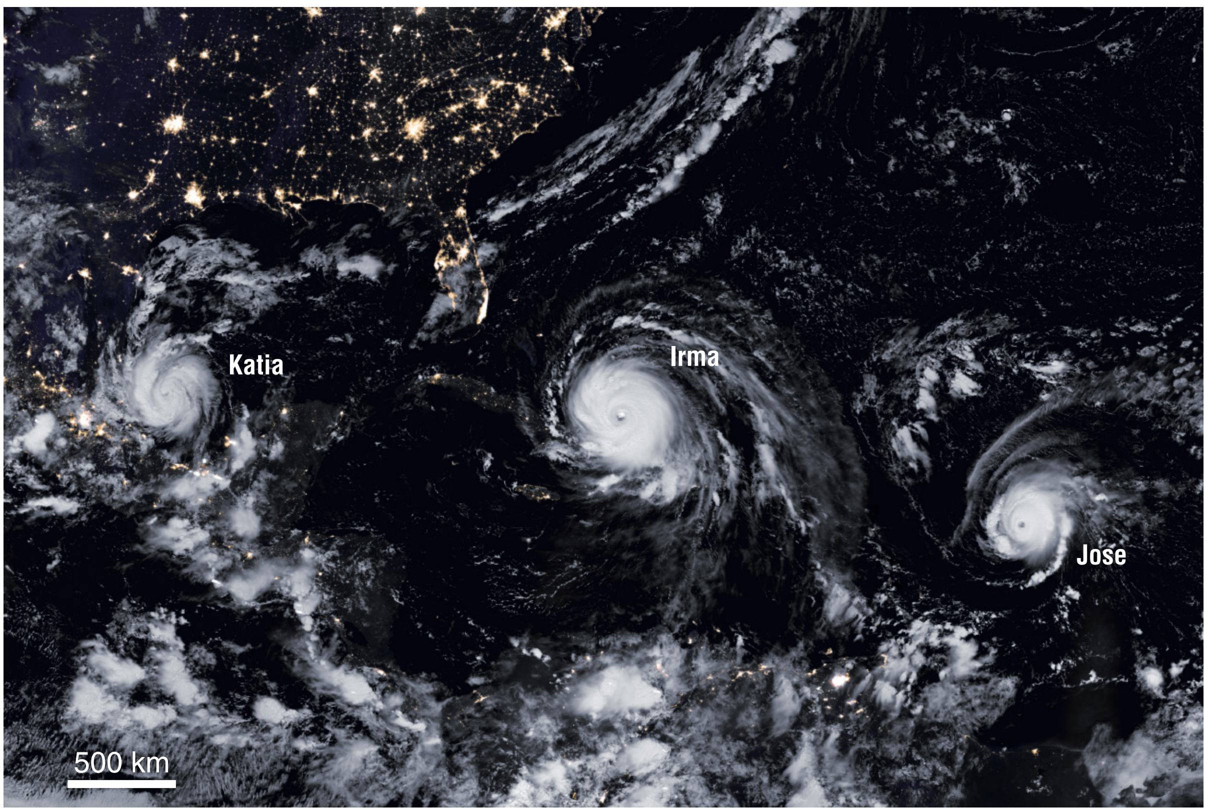
Forecasters were most concerned about Irma, which was on track to make landfall in densely populated South Florida on September 10 as a large category 4 storm.[1] Meanwhile, Category 2 Hurricane Katia was headed for Mexico, where it was expected to make landfall on September 9.[2] And just days after Irma devastated the Leeward Islands, the chain of small Caribbean islands braced for another blow—this time from Category 4 Hurricane Jose.[3]

The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi NPP satellite captured the data for a mosaic of Katia, Irma, and Jose as they appeared in the early hours of September 8, 2017. The images were acquired by the VIIRS "day-night band," which detects light signals in a range of wavelengths from green to near-infrared, and uses filtering techniques to observe signals such as city lights, auroras, wildfires, and reflected moonlight. In this case, the clouds were lit by the nearly full moon. The image is a composite, showing cloud imagery combined with data on city lights. ■

[1] On September 5, Irma was labeled as an "extremely dangerous" Category 5 storm. Irma passed north of the Dominican Republic on September 7. This historically intense hurricane—which maintained winds of 185 mph longer than any storm ever recorded on Earth—made landfall on Cuba's Camaguey archipelago as a Category 5 hurricane on September 8, again at Cudjoe Key in lower Florida Keys as a Category 4 on September 10, and a final time on Marco Island in Florida later that day as a Category 3 storm.

[2] Katia shortly became a Category 2 storm on September 8, making landfall later that evening as a Category 1 storm north of Tecolutla, Mexico.

[3] Jose became a Category 1 storm on September 6 and rapidly intensified into a Category 4 storm by September 8. It remained a Category 4 storm until September 10. As of September 12, Jose was a Category 1 storm.




This image, created using data from the Visible Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite, shows hurricanes Katia [*left*], Irma [*middle*], and Jose [*right*] lined up across the Atlantic basin on September 8, 2017. **Credit:** NASA's Earth Observatory

# NASA Earth Science in the News

*Samson Reiny, NASA's Earth Science News Team, samson.k.reiny@nasa.gov*

**What Could We Lose if a NASA Climate Mission Goes Dark?,** September 12, *nytimes.com*. In late August, as Hurricane Harvey began smashing into the Texas coast, a flood of data began pouring in along with the catastrophic quantities of rainwater. It wasn't from the nonstop news coverage on CNN and elsewhere; it was from the transmissions that lay behind it, in the pulses of information coming down from space. The National Oceanic and Atmospheric Administration's geostationary and polar-orbiting satellites, crucial tools for monitoring big storms, captured cloud formations, surface temperatures, and barometric pressures, which were then fed into computer models tracking the storm's strength and intensity. At the same time, NASA utilized its own set of Earth-observing satellites to keep tabs on soil moisture, flood patterns, and power failures all over East Texas. In various ways, this torrent of data was being collected continuously from hundreds to thousands of miles overhead, through radar instruments and spectroradiometer sensors, and through exquisitely calibrated imaging cameras. The machines being used aren't household names—they go by acronyms like GOES-13, MODIS, and SMAP[1]—but they demonstrate why the popular view of Earth as a big blue planet with only the moon as its companion, could do with some revising. We are also surrounded by a constellation of satellites spinning elliptical webs of environmental observation, day and night.

**Hurricane Irma Wipes Out So Many Plants in the Caribbean that Entire Islands Changed Color,** September 12, *businessinsider.com*. Sometimes devastation is best viewed from above. NASA's Earth Observatory has released an astonishing set of images that show the stark contrast between what islands in the Caribbean looked like before and after Hurricane Irma struck—see **Figure 1**. Barbuda, Anguilla, the Virgin Islands, and Cuba were hit by the worst of the storm, with some islands reporting that 90% of their structures were damaged or destroyed. The natural-color images shown below were captured by the Landsat 8 satellite before and after the storm hit. According to **Kathryn Hansen** [NASA's Goddard Space Flight Center], the visible browning of the islands could have been caused by fierce winds, which reached speeds of 185 mph (~298 km/hr) and uprooted plants and trees from the Earth. The salt spray whipped on to the island by the hurricane also likely dried out the leaves on trees—causing them to turn brown.

***NASA Satellites are Tracking Katia, Irma, and Jose and the Images are Staggering**, September 9, *cnbc.com*. NASA is leveraging its fleet of domestic and international satellites to help track the current lineup of hurricanes gathering steam and heading towards the U.S. The satellites are tracking rainfall, wind speeds, temperatures, and position. The images are staggering both because of the technology required to obtain them and the size and scope of the storms they depict. The government's preeminent space agency leverages terabytes of data to help inform and protect people and infrastructure in times of disaster in a program called the NASA Earth Science Disasters Program.

**Harvey Response: NASA Lends Space-Based Eyes to Recovery,** August 31, *space.com*. NASA is aiding the

[1] GOES-13 stands for Geostationary Operational Environmental Satellite-13; MODIS stands for Moderate Resolution Imaging Spectroradiometer; SMAP stands for Soil Moisture Active Passive.

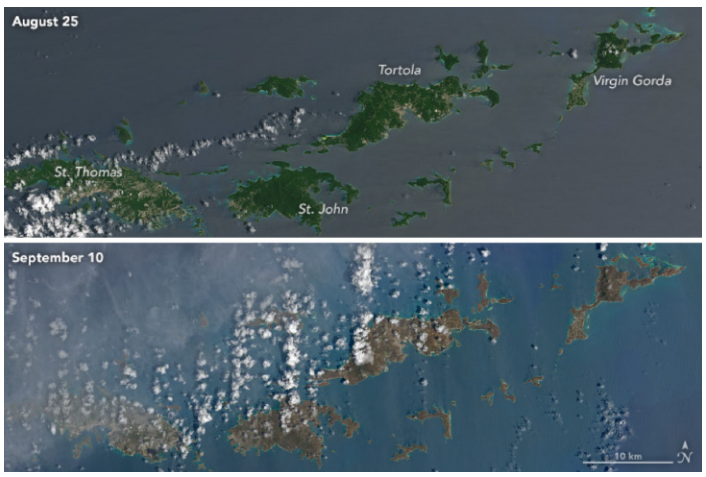



**Figure 1.** These images, captured by the Operational Land Imager (OLI) on the Landsat 8 satellite, show some of Irma's effect on the British and U.S. Virgin Islands. The views were acquired on August 25 and September 10, 2017, before and after the storm passed. **Credit:** NASA's Earth Observatory

humanitarian response to Tropical Storm Harvey by surveying the storm's impact from above. This effort will provide expert data to relief agencies. Harvey first hit southeastern Texas on August 25 as a Category 4 hurricane, and made landfall in southern Louisiana as a tropical storm on August 30. The storm system lingered in the region, causing flooding and record-breaking rainfall. The downpour was so immense that the National Hurricane Center called the flooding "life-threatening." NASA is assisting local, state, and federal emergency managers and first responders by using its spacecraft to take measurements of the affected region, according to a new statement from the agency. "This is an immense weather event that is creating a unique challenge," **Thomas Zurbuchen** [NASA Headquarters—*Associate Administrator for the Science Mission Directorate*] said in the statement. "NASA is working to enable and enhance the capabilities of our partners across federal agencies and elsewhere to ensure [that] they are able to do the best job possible in assessing the threat and providing rescue and response services."

**NASA's IMERG Shows Rainfall Accumulations Along Harvey's Track,** August 29, *phys.org*. As Harvey continues to dump catastrophic rains over southeastern Texas and southwestern Louisiana, NASA has been tallying rainfall accumulations in the storm's wake. Total rainfall estimates from NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) data were compiled for the period from August 23 to 29, 2017—see **Figure 2**. During this period, Harvey dropped heavy rainfall as it moved through the Gulf of Mexico and stalled over Texas. The IMERG totals showed over 30 inches of rainfall in the Houston metro area and part of the western Gulf of Mexico. It has been reported that Harvey dropped over 40 inches of rain over southeastern Texas during this period. IMERG data are produced at NASA's Goddard Space Flight Center, using data from the satellites in the Global Precipitation Measurement (GPM) mission constellation, and is calibrated with measurements from the GPM Core Observatory as well as rain gauge networks around the world.

**Hottest July and Hottest Month, On Record,** August 15, *thinkprogress.org*. July 2017 has narrowly topped July 2016 as the hottest July on record, according to analysis by scientists at NASA's Goddard Institute for Space Studies (GISS). As a result, July 2017 is statistically tied with August 2016 (and July 2016) as the hottest month on record. What's so surprising here is that records for warmest month or year almost invariably occur when the underlying human-caused global warming trend gets a temporary boost from an El Niño's enhanced warming in the tropical Pacific. But whereas 2016 set its temperature records boosted by one of the strongest El Niño's on record, 2017 is setting records in the absence of any El Niño at all.

**NASA Airborne Mission Returns to Africa to Study Smoke, Clouds,** August 10, *phys.org*. NASA's P-3 research plane begins flights in August through both clouds and smoke over the South Atlantic Ocean to understand how tiny airborne particles called *aerosols* change the properties of clouds and how they influence the amount of incoming sunlight the clouds reflect or absorb. The Observations of Aerosols above Clouds and their Interactions (ORACLES) field mission is carrying out the month-long field campaign from São Tomé and Principe, an island nation off the west coast of Africa. The sheer variety of aerosol particle types and the fact that they stay in the atmosphere for days to weeks, compared to years spent by greenhouse gases, means they are among the most challenging to understand and incorporate into climate models, said **Jens Redemann** [NASA's Ames Research Center—*ORACLES Principle Investigator*], which is why the data collected from the P-3 aircraft are so important.

*See News Story in this issue.

*Interested in getting your research out to the general public, educators, and the scientific community? Please contact **Samson Reiny** on NASA's Earth Science News Team at **samson.k.reiny@nasa.gov** and let him know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of **The Earth Observer**.* ■

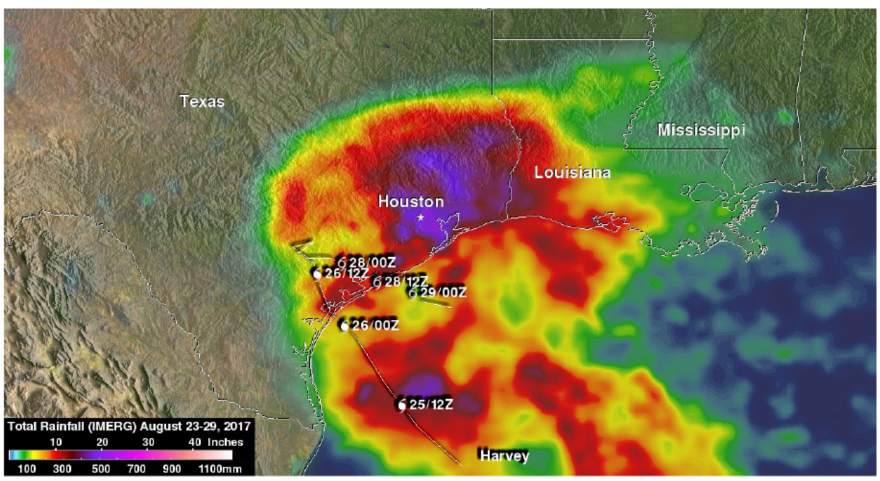



**Figure 2.** This image shows total rainfall estimates from NASA's Integrated Multi-satelliE Retrievals for GPM (IMERG) data for the period August 23-29, 2017. **Credit:** NASA

## EOS Science Calendar

**October 23–27, 2017**
Ocean Surface Topography Science Team Meeting, Miami, FL.
*https://cpaess.ucar.edu/meetings/2017/ocean-surface-topography-science-team-meeting-ostst*

**January 23–26, 2018**
ABovE Science Team Meeting, Seattle, WA
*https://above.nasa.gov/meetings.html*

**March 19–23, 2018**
2018 Sun-Climate Symposium, Lake Arrowhead, CA.
*http://lasp.colorado.edu/home/sorce/news-events/meetings/2018-scs*

**June 4–6, 2018**
ASTER Science Team Meeting
Tokyo, Japan

## Global Change Calendar

**October 22–25, 2017**
Geological Society of America Annual Meeting, Seattle, WA.
*http://community.geosociety.org/gsa2017/home*

**December 11–15, 2017**
AGU Fall Meeting, New Orleans, LA.
*http://fallmeeting.agu.org/2016/2017-fall-meeting-new-orleans*

**January 7–11, 2018**
AMS 98th Annual Meeting, Austin, TX.
*https://annual.ametsoc.org/2018*

**February 11–16, 2018**
Ocean Sciences Meeting, Portland, OR.
*http://osm.agu.org/2018*


In the latest twist from an unusually potent Atlantic hurricane season, Hurricane Ophelia headed for the shores of Ireland in October 2017. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this image of Ophelia at 12:55 PM local time (11:55 UTC) on October 16, 2017. Hurricane Ophelia weakened and devolved into a post-tropical cyclone on the evening of October 15, 2017. However, the storm maintained enough strength to deliver destructive winds and rain to Ireland and the United Kingdom the next day. This storm is unusual in that it formed and stayed in the eastern Atlantic. Typically, hurricane remnants that impact this area track west from Newfoundland and the Canadian Maritimes. **Credit:** NASA's Earth Observatory

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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## The Earth Observer Staff

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| Executive Editor: | Alan B. Ward (alan.b.ward@nasa.gov) |
| Assistant/Technical Editors: | Heather H. Hanson (heather.h.hanson@nasa.gov)<br>Mitchell K. Hobish (mkh@sciential.com) |
| Technical Editor: | Ernest Hilsenrath (hilsenrath@umbc.edu) |
| Design, Production: | Deborah McLean (deborah.f.mclean@nasa.gov) |

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